THICKENING OF MUNICIPAL SLUDGE AND TREATMENT OF LEACHATE USING RECYCLED FERROUS SULPHATE (RFS) EXTRACTED FROM GROUNDWATER TREATMENT PLANT SLUDGE

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Dissertation submitted in partial fulfilment of
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CERTIFICATION OF APPROVAL

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Approved by.

(Assoc. Prof. Dr Shamsul Rahman Mohamed Kutty)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MAT SAHNIZAM BIN TAMAT

ABSTRACT

The suitability and effectiveness of recycled ferrous sulphate (RFS) extracted from groundwater treatment sludge to improve settleability of municipal sludge and treatment leachate was investigated in this study. The groundwater sludge was taken from Chicha Water Treatment Plant, Kelantan. Since the groundwater sludge contains non-hazardous metal like iron and manganese, it cannot be discharge plainly without proper treatment because if happen, it may lead to the pollution of surface water and ground water system and thus, create the environmental problem. The study involved the experiment to use the RFS as a coagulant material for settleability improvement in sewage municipal sludge's treatment and the result is compared to the other commercial coagulants which are alum ($Al_2(SO_4)_3$), ferrous sulphate ($FeSO_4$), and ferric chloride ($FeCl_3$). Apart from settleability, the study also focused on the RFS efficiency on removal of Chemical Oxygen Demand (COD), Color, and Total Suspended Solid (TSS) in the leachate treatment. As a result, RFS proved to be a better coagulant for sludge settleability which recorded 5.15 cm/min and performance increased by 115%, compared to alum 4.8 cm/min (100% efficiency), $FeCl_3$ 3.875 cm/min (62% efficiency), and $FeSO_4$ 3.75 cm/min (56% efficiency). In leachate treatment, $FeCl_3$ is the best coagulant in COD removal since it recorded 68% efficiency, followed by RFS (67% efficiency), alum (36% efficiency), and $FeSO_4$ (20% efficiency). For Color parameter, alum is the best coagulant since it recorded 90% removal, followed by RFS (88%), $FeCl_3$ (64%), and $FeSO_4$ (27%).

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1.0

INTRODUCTION

1.1 Background

The increasing production of sludges derived from the groundwater treatment plant causes a new environmental problem due to their final disposal. The current sludge disposal treatment is not effective since the production is increasing and very costly to maintain its effectiveness. The sludge regulations limit sludge disposal on the basis of the treatment level provided, pathogen removal, and metals content. These regulations encourage biosolids use, thus significant efforts have been directed to producing a "clean sludge". It is more practical to dispose sludge in a manner that involves some form of reuse of the product, whether by direct land application, stabilization, composting, or pelletizing [1].

The groundwater treatment plant produced sludge which contain high amount of iron as source from the ground has high Fe. To enhance the reuse of sludge, the use of recovered iron from the groundwater treatment plant's sludge to improve settleability of municipal sludge was investigated in this study by using sludge from Chicha Water Treatment Plant in Kelantan. The iron content was recovered by digestion process with sulphuric acid to produce RFS (Recycled Ferrous Sulphate). Besides the settleability improvement in the first phase of the study, the second phase focused on the leachate treatment produced by Pulau Burung Landfill Site (PLBS) situated in Penang, Malaysia. The leachate collected is a raw sample without any treatments. The performance of RFS then is compared to other commercial coagulants which are alum, ferrous sulphate, as well as ferric chloride.

1.2 Problem Statement

The increasing production of groundwater sludge derived from water treatment plant causes a new environmental problem due to their final disposal. This groundwater sludge contains metals such as iron and manganese. However, it cannot simply be disposed into the river or any other place without proper treatment because it may lead to pollution of surface water and ground water system such as taste, staining, and accumulation problems.

1.3 Objective and Scope of Study

The objectives of this project are:

1) To study whether groundwater sludge can be recycled or not.
2) To measure the effectiveness of RFS in thickening of sewage sludge process.
3) To measure the effectiveness of RFS in leachate waste treatment.

The scope of work for this project is to conduct an experimental research including:

1) Groundwater sludge digestion using sulphuric acid to produce Recycled Ferrous Sulphate (RFS).
2) Measurement of the iron Fe^{2+} and total Fe concentration produced from groundwater sludge digestion by acid sulphuric.
3) Settleability rate measurement for sewage sludge with and without treatment of RFS and other commercial coagulants which are alum, FeCl3, and $FeSO_4$.
4) Percentage removal for several parameter in sewage sludge and leachate waste treatment after applying the RFS and other coagulants which are Chemical Oxygen Demand (COD), Colour, Turbidity, and Total Suspended Solid (TSS).

CHAPTER 2.0

LITERATURE REVIEW AND THEORY

2.1 Groundwater Treatment Plant Sludge Characterization

Groundwater treatment plant sludge is defined as the accumulated solids or precipitate removed from a sedimentation basin, settling tank, or clarifier in a groundwater treatment plant. The accumulated solids are the result of chemical coagulation, flocculation, and sedimentation of raw water [2]. Because of high iron and manganese content in the water treatment sludge, the proper disposal process requires high cost in order to prevent any pollution to the environment. Thus, instead dispose, the study suggest an alternative to reuse the sludge to something beneficial for wastewater treatment field.

2.2 Municipal Sludge Characterization

Municipal sludge is the natural products of a microbial food chain in the wastewater treatment process. Microbes feed on organic components of waste until they can no longer derive energy from it. At this point, sludge consists of mostly cellular material and stable degradation products that are considered safe for application to agricultural or forest lands [3].

Basically, land application is an excellent way to dispose of sludge. Waste can be applied at rates to meet crop nutrient requirements without harming the environment. Both the waste generator and the crop producer benefit from this recycling system. Humans and animals are natural waste generators, and land application makes it possible to recover the valuable components of waste as a usable resource.

Normally, sludges contain nutrients that are beneficial to plants, but heavy metals or other potentially toxic substances may also be present. These substances must be reduced or confined to levels that are considered safe for the environment. The study of settleability after treated by RFS and other coagulants used the effluent sample of UTP Wastewater Treatment System.

2.3 Leachate Characterization

Leachate is a complex organic liquid formed primarily by the percolation of precipitation water through open landfill or through the cap of the completed site [4]. Leachate may contain large amount of contaminants which can be measured by Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), suspended solid, and heavy metals as well. If leachate is not well treated, it may infiltrate into soils and subsoils thus causing pollution to water stream.

There are various ways in leachate treatment and the best is physical/chemical process [5]. Chemical precipitation using lime indicated that between 70% and 90% removal of color, turbidity, suspended matter and dispersed oil could be achieved [6]. Coagulation and flocculation is widely used in water and wastewater treatment and these techniques form an important step in the treatment process [7].

In leachate treatment, $FeCl_3$ was found to be superior compared with other coagulants like alum and $FeSO_4$. The result showed that higher removals of suspended solids are over 95%, colour (90%) and COD (43%) achieved at pH 4 and 12 [4].

2.4 Thickening of Municipal Sludge

Thickening is the process to increase the solid content of sludge by removing a portion of the liquid fraction. The primary purpose of sludge thickening is a volume reduction. The volume reduction obtained from thickening is beneficial to subsequent treatment processes such as digestion, dewatering, drying, and combustion. In addition, thickening also reduces the required capacity of downstream tanks and equipment, the quantity of chemicals required for conditioning, the heat required by digesters and the volume of sludge to be transported, dried, incinerated, and disposed of. Thickening procedures can be applied at various stages of the sludge treatment process, but is mostly done with primary and activated sludge before stabilization. Thickening is generally accomplished by physical means, using either natural gravitational forces or mechanical forces [8].

Talc and polymer are proven additives that could improve the thickening process [9]. In other study, amphoteric polymer is added to pelletize the sludge and reduce the retention time of the sludge in the system to only 10 to 20 min, as compared to about 12 h when conventional thickeners are used. Suspended solids recovery was more than 95% with slits spaced 1.0–1.5 mm apart [10].

Typical technologies for sludge thickening are gravity settling, flotation, rotary drum thickener, gravity belt thickener, and decanter-centrifuges. Often flocculation agents are added to improve thickening characteristics. This conditioning change sludge characteristics, so that the water discharge rate of the sludge is improved.

2.5 Dewatering of Municipal Sludge

Dewatering is a physical or mechanical unit operation used to achieve the highest possible dried solids content, reduce sludge volume and improve stability of the sludge [8]. It is the basic requirement to reduce cost for transportation, disposal, and possible thermal treatment of the sludge. The amount of water that can be separated during dewatering depends on the chemical, structural and physical characteristics of flocs [11]. Basic methods of sludge dewatering are by filtration and generating an artificial gravitational field [8].

Alum flocs are larger and more compact than ferric, thus they settle faster and lead to sludges containing about 20% more bound water but having lower resistance to water removal. Ferric flocs contain about 20% less bound water but exhibit higher Capillary Suction Time (CST) values and therefore higher resistance to water removal than alum [11].

2.6 Coagulation Process

Coagulation is the destabilization of the colloids by neutralizing the forces that keep them apart objectively to thicken the sludge. A wide range of coagulants exists and the most common are aluminum sulfate, ferric chloride, ferrous sulfate, and polyaluminum chloride. Powdered activated carbon (PAC), a coagulation aid, can be used in coagulation cells to enhance the removal of taste and odour compounds, and remove some organic carbon. Since many problems are associated with ferrous sulfate, ferric chloride is the iron salt used most commonly in precipitation applications [12].

There are two main types of coagulant chemicals which are primary coagulants and coagulant. Primary coagulants neutralize the electrical charges of particles in the water which causes the particles to clump together and are always used in the coagulation or flocculation process. Coagulant add density to slow-settling flocs and add toughness to the flocs to ensure that they will not break up during the mixing and settling processes. They are not always required and are generally used to reduce flocculation time [13].

Basic reactions occur during coagulation process involving $FeSO_4$ in the leachate is shown by the following equations:

$$FeSO_4 + 2HCO_{3-} \leftrightarrow Fe(OH)_2 (\downarrow) + (SO_4)_{2-} + 2CO_2 \qquad [4]$$

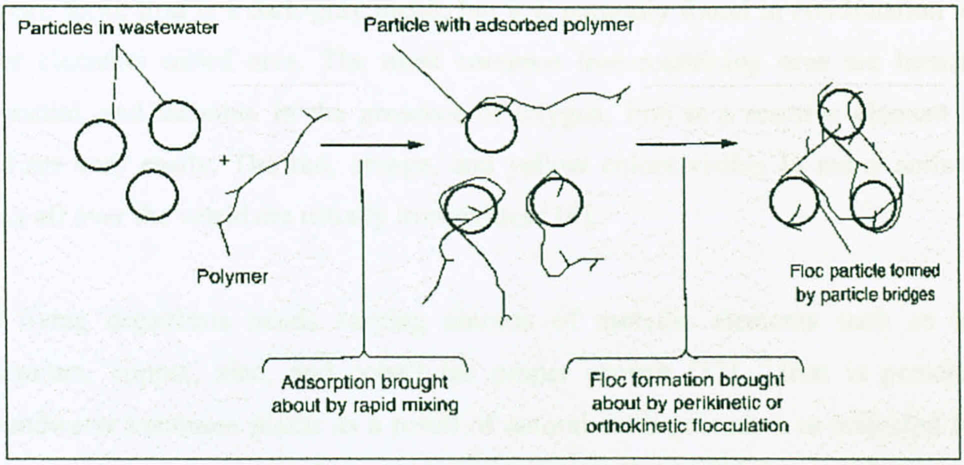

Figure 2.1: Inter Particles Bridging With Organic Polymers.

2.7 Alum as Coagulant

Aluminum Sulfate widely known as alum, filter alum, and alumina sulfate is the most widely used coagulant. Alum is available in dry form as powder, or in lump form. Alum has no exact formula due to the varying water molecules of hydration which may be attached to the aluminum sulfate molecule [14]

Dry alum is available in several grades, with a minimum aluminum content (expressed as $\%Al_2O_3$) of 17%. Liquid alum is about 49% solution, or approximately 8.3% by weight aluminum as Al_2O_3. Alum coagulation works best for a pH range of 5.5 to 8.0; however, actual removal efficiency depends on competing ions and chelating agent concentrations [15].

Once in water, alum can react with hydroxides, carbonates, bicarbonates, and other anions to form large, positively charged molecules. These reactions produce carbon dioxide and sulfate. During the reactions, alum acts as an acid to reduce the pH and alkalinity of the water supply. It is important that sufficient alkalinity be present in the water supply for the various reactions to occur [14].

2.8 Iron Coagulant

Iron (Fe) is a metallic element that makes up about 5 percent of the Earth's crust. In its pure form, iron is a dark-gray metal, but it is naturally found in combination with other elements called ores. The most common iron-containing ores are hematite, magnetite, and taconite. In the presence of oxygen, iron is a reactive element that oxidizes very easily. The red, orange, and yellow colors visible in many soils and rocks all over the world are usually iron-oxides [16].

All living organisms needs varying amount of metallic elements such as iron, chromium, copper, zinc, and cobalt for proper growth [12]. Iron is present in groundwater treatment plants as a result of natural earth processes or collected from corroded pipes through out the water piping system. Rainwater filtrated through soil and rocks dissolves minerals containing iron and holds them in solution. The amount of iron that will dissolve during the percolation process depends on the water's hardness and acidity. These iron-rich waters will flow to surface waters and aquifers and eventually will serve as drinking water sources. Iron is always present in most drinking water at concentrations not greater than 10 parts per million. Commonly, corrosion also can be a source of iron in water treatment plants. Iron contamination as a result of corroded pipes is a common occurrence in many cities that have very old water systems [16].

Iron is considered a secondary household water contaminant with no health problems at concentrations normally found in household drinking water. Presence of iron in drinking water can be identified by the staining of plumbing fixtures and clothing, as well as an unpleasant taste and odor. Iron can be present in drinking water in several different forms which are ferrous iron, ferric iron, iron bacteria and organic iron; therefore, testing of the water supply is essential before choosing water treatment equipment. Iron is regulated under the Secondary Maximum Contaminant Level (SMCL) standard. No treatment methods will work on all four forms of iron [16].

Standard for iron is based on levels that cause taste and staining problems and are set under EPA Secondary Drinking Water Standards. The iron limit in drinking water is 0.3 milligrams per liter (mg/L), or 0.3 parts per million (ppm). Usually iron does not exceed 10 ppm in natural waters but it may range from 0 to 50 mg/L in groundwater. Iron is found at higher concentrations; however, that condition is rare [17].

Iron coagulants include ferrous sulphate, ferric chloride, and ferrous sulphate (copperas). Compared to aluminum derivatives, iron coagulants can be used successfully over a much broader pH range of 5.0 to 11.0. However, when ferrous compounds are used, the solution is typically chlorinated before it is sent into the coagulation vessel. As this reaction produces both ferric chloride and ferrous sulphate, chlorinated ferrous sulphate has the same field of usefulness as the other iron coagulants. Because ferrous sulphate works better in feeding devices, compared with the ferric coagulants, chlorinated copperas is sometimes preferred. The ferric hydroxide floc is heavier than alum floc and therefore settles more rapidly [15].

On the other hand, recovered ferric sulphate showed good result in the treatment of two different types of wastewaters from textile industry in Iran [18]. Results obtained using the recovered iron salt is about 40 to 85 percent decrease in total COD of two different kinds of textile wastewaters while total suspended solids removal is reported to be 60 to 82 percent [18]. In treating raw influent obtained from a sewage treatment plant and wastewater from a coastal landfill site, the removal of chemical oxygen demand (COD), total nitrogen, and total phosphorous with the recovered coagulant was higher than that with commercial aluminum sulfate or polyaluminum chloride [19].

Table 2.1: The Advantages and Disadvantages of Using Various Iron Coagulants.

Name	Advantages	Disadvantages
Ferric Sulfate $Fe_2(SO_4)_3$	Effective between pH 4–6 and 8.8–9.2	Adds dissolved solids (salts) to water; usually need to add alkalinity
Ferric Chloride $FeCl_3.6H_2O$	Effective between pH 4 and 11	Adds dissolved solids (salts) to water; consumes twice as much alkalinity as alum
Ferrous Sulfate (Copperas) $FeSO_4.7H_2O$	Not as pH sensitive as lime	Adds dissolved solids (salts) to water; usually need to add alkalinity

CHAPTER 3.0

METHODOLOGY

3.1 Groundwater Treatment Plant Sludge Characterization

The constituents in the groundwater treatment plant sludge are determined by X-Ray Diffraction (XRD) Test and X-Ray Fluorescence (XRF) Test.

3.1.1 X-Ray Diffraction (XRD) Test

X-Ray Diffraction (XRD) Test is a method used to analyze the compound of the sludge. A number of reciprocal space maps were taken over the surface of the grown wafer, and variations in the spread of lattice spacing and tilts were quantified and used to identify the presence of local defects. Though all growths were fully strained, those with a larger mismatch exhibited a greater spread of lattice tilts from the substrate to the superlattice layers in both orientations [20]. Mineralogical characterization of selected chemically stabilized sludge was conducted on powdered samples by X-ray diffraction (XRD) using a diffractometer with Co Kα radiation. Specimens were scanned from 4 to 54°2θ [21]. From the XRD Test conducted, the groundwater treatment plant sludge contains at least four constituents, which are aluminium oxide, calcium oxide, silica oxide, and iron (III) oxide (Appendix A1).

3.1.2 X-Ray Fluorescence (XRF) Test

X-Ray Fluorescence (XRF) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. It is the method use to identify the element in the sludge. X-ray fluorescence analysis was applied to study the iron content in the samples. The instrument has a titanium target X-ray tube and a high-resolution detector. The sample was studied in a solid phase after grinding and sieving in order to use the matrices with similar physical properties [22]. From the XRF Test result, groundwater treatment plant sludge contains 30.4% calcium oxide, 23.3% ferric oxide, 11.5% silica oxide, 4.6% aluminium oxide, and small portion of others elements as well. The result confirmed that there are iron element in the groundwater treatment plant sludge that can be digested to produce recycled iron coagulant (Appendix A2).

3.2 Groundwater Sludge Extraction

The raw groundwater sludge sample is wet. Hence, before proceed, the sludge will be dried in the oven at 150°C for one day and then grinded to have the possible fine granular sample. Fine sample is easier and faster to be digested instead of a bigger sample.

Figure 3.1: Groundwater Sludge after Dried and Grinded

3.3 Groundwater Sludge Digestion

In order to produce very high concentration of RFS, digestion was required to dissolve the iron. This experiment required a 10% solution. In order to achieve this, the concentration of the solution prepared was at 100 000 mg/L. This was obtained by digesting 50 g of sludge with 500 ml of distilled water and continuous addition of sulphuric acid.

A 1000 ml beaker was used and rinsed with water. 50 ml of sulphuric acid (H_2SO_4) was added. Boiling chips were also added to aid boiling and minimize spatter when high concentration levels were being determined. On a hot plate, the mixture was stirred at low temperature while adding more sulphuric acid at suitable intervals. The mixture was allowed to evaporate to the lowest volume possible until digestion was completed indicated by a light-colored, clear solution. Finally, the solution was filtered and the concentration of iron Fe^{2+} was checked using spectrophotometer. The concentration of iron Fe^{2+} from this experiment was only 600 mg/L (0.06 %).

Figure 3.2: Groundwater Sludge Digestion

3.4 Settleability Test

This study is to determine the effectiveness of various coagulants on the sludge settling and to identify the best settleability performances for each respective coagulant. Sewage sludge is taken from UTP Sewage Treatment Plant. Each sample of coagulant (Alum, $FeCl_3$, $FeSO_4$, and RFS) is added to the sludge by applying jar test method. Standard jar test was used in the laboratory experiment. The procedures included one minute for rapid mixing, and followed by 30 minutes of slow mixing.

After each completion of jar test, the solution will be poured in the 1 L cylindrical beaker to measure the settling rate of the groundwater sludge. The height of the initial solution until it settled was taken with respect to the time needed. The settleability calculation is determined from the slope of the tangent drawn from the initial portion of the interface settling curve. The computed velocity represents the unhindered settling rate of the sludge. The result then is compared with the raw sewage sludge settleability (without any coagulant added) whether there is improvement or not.

Supernatant produced after sludge settled was taken for determination of Chemical Oxygen Demand (COD), colour, turbidity and total suspended solid (TSS) tests.

3.5 Chemical Oxygen Demand (COD) Test

Chemical oxygen demand (COD) test was used to indirectly measure the amount of organic compounds in water. It is expressed in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution. A commonly used oxidant in COD is potassium dichromate ($K_2Cr_2O_7$) which is used in combination with boiling sulfuric acid (H_2SO_4). 2 mL of sample is put into COD vial, stirred and heated at 150°C for 2 hours. Spectrophotometer was used to measure the COD reading.

3.6 Total Suspended Solid (TSS) Test

TSS is solid materials, including organic and inorganic, that are suspended in the water. High concentrations of suspended solids can lower water quality by absorbing light. Waters then become warmer and lessen the ability of the water to hold oxygen necessary for aquatic life.

TSS was determined by filtering the supernatant using 45 μm filter paper, then weight the filter paper and dried in the oven at 105 °C for 30-45 minutes before weighting again the filter paper.

The formula for TSS (mg/L) is = $\dfrac{\text{Final Weight} - \text{Initial Weight (mg)}}{\text{Sample Volume in L}}$

3.7 Color Test

Color test is measurement of water concentration that directly proportional to color development and intensity after addition of chemicals or treatment. The color of water is usually compared to platinum cobalt color standards representing APHA Standard

Color Units. Sample of 10 mL is taken and compared to standard color-free sample. The reading is recorded using spectrophotometer.

3.8 Hazard Analysis

The project conducted must comply with the UTP standard Health, Safety, and Environment (HSE) rules and regulations. The objective are to prevent accident, to avoid any harm to students and people surrounding, to prevent properties damage and loss event, and to take care of university image and performance.

As far as the project is concern, it is an experimental research type that dealing with various chemical solutions and mostly conducted in the Environmental Laboratory. Hazard analysis must be prepared to ensure the necessary action has been taken care before, during, and after the related experiment is done.

Hazard analysis is the process of study and identifies anything that can cause harm such as chemical, electricity, noise etc. The finding of hazard identification should result in a list of hazard sources, the particular form in which that hazard occurs, the areas of workplace or work process where it occurs and the persons exposed to that hazard. Thus, from the analysis, the precaution action will be taken to reduce the probability of harm that may be dangerous to the respective people involved in the project.

The possible hazards identification and precaution relevant to the project are tabulated in the table below:

Table 3.1: Possible Hazard Identification and Precaution

Hazard	Effects	Precaution Action
Sulphuric Acid	Irritation eyes, skin, nose, throat; pulmonary edema, bronchitis; emphysema; conjunctivitis; stomatis; dental erosion; eye, skin	Wear Personal Protective Equipment (PPE), prevent eye and skin contact, conduct experiment in fume

	burns; dermatitis	cupboard, irrigate and water flush immediately if contact
Ferrous Sulphate	Irritation eyes, skin, mucous membrane; abdominal pain, diarrhea, vomiting; possible liver damage	Wear PPE, prevent skin and eye contact, soap wash if contact
Groundwater sludge	Expose to chemical splashes, taste, staining, accumulation	Wear PPE
Leachate	Breathing, expose to chemical splashes	Wear PPE, mask to avoid odour

CHAPTER 4.0

RESULTS AND DISCUSSION

4.1 Phase 1: Thickening of Municipal Sludge Using RFS

4.1.1 Groundwater Sludge Digestion

In the first phase of project, first experiment is optimization of sludge digestion to determine the optimum dosage of sulphuric acid required in order to get a maximum iron ferrous concentration. Six beakers with different H_2SO_4 volume (2 mL to 12 mL) was analysed using sludge digester. The result was shown in Appendix A2. Figure 4.1 below is the graph formed from the result.

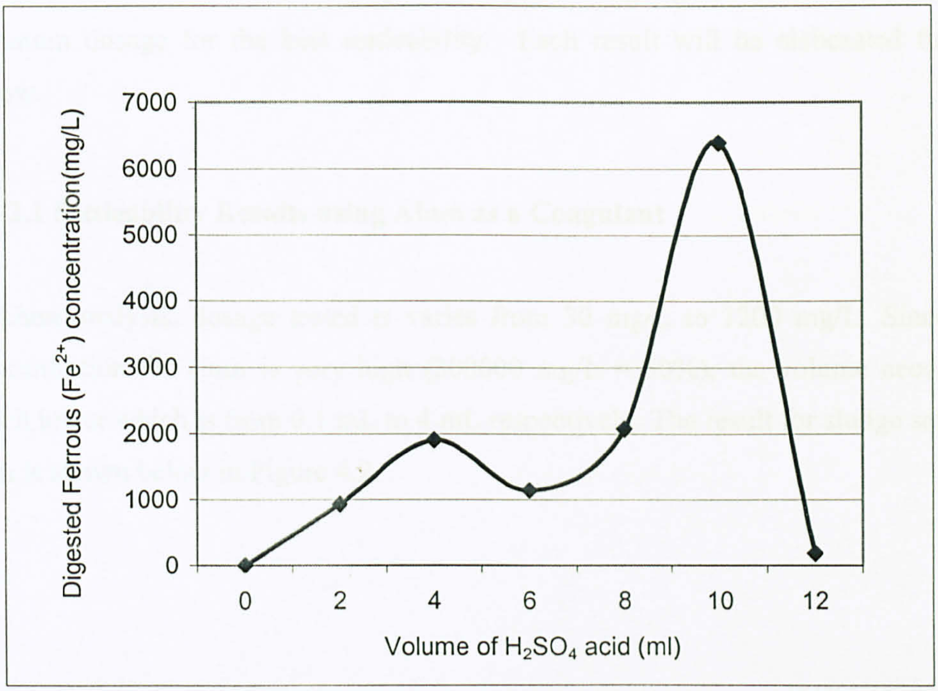

Figure 4.1: Graph of Iron Fe^{2+} Concentration versus H_2SO_4 Dosage

The graph result showed that the optimum dosage for sulphuric acid content is 10 mL with dilution to 2500 mL of distilled water. The iron Fe^{2+} concentration digested from that amount is 6394 mg/L (0.64% Conc.) which is the highest concentration.

Thus, to produce 10% solution or 100000 mg/L iron Fe^{2+} concentration, the amount needed for sludge is 50 g with 500 mL of distilled water and 10 mL sulphuric acid. However, in the exact sludge digestion experiment, the amount of sulphuric acid used was 50 mL with the assumption that more acid will digest more iron Fe^{2+} concentration.

4.1.2 Settleability Results

The result for the settling rate measurement then is shown in Appendix B1. Initial settleability measurement for raw groundwater sludge was 2.4 cm/min (refer Appendix B2). The settleability is improved after coagulants added which increased between 56% to 115% efficiency. The yellow highlighted table indicated the optimum dosage for the best settleability. Each result will be elaborated further below.

4.1.2.1 Settleability Results using Alum as a Coagulant

In alum analysis, dosage tested is varies from 30 mg/L to 1200 mg/L. Since the concentration for alum is very high (300000 mg/L = 30%), the volume needed is much lower which is from 0.1 mL to 4 mL respectively. The result for sludge settling then is shown below in Figure 4.2.

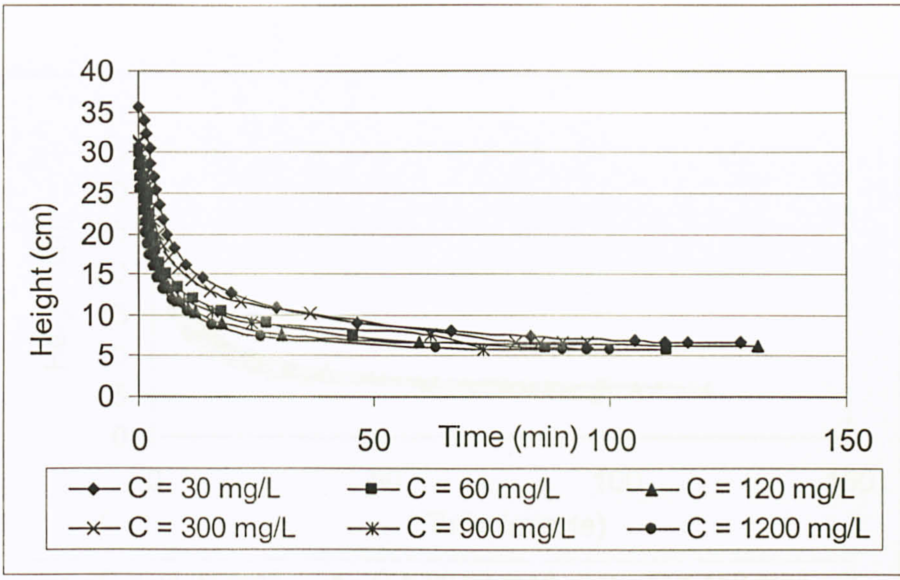

Figure 4.2: Graph of Height versus Time of Alum with Different Dosage

The graph showed that all dosage of alum resulted in same shape of line and those are acceptable. From the calculation for each sample line, the highest gradient for sludge settleability using alum was 4.8 cm/min on Sample 5 which used 900 mg/L dosage of alum. Other samples settleability result varies from 2.769 cm/min to 4.75 cm/min as in Appendix B3.

4.1.2.2 Settleability Results using Ferrous Sulphate as a Coagulant

In ferrous sulphate analysis, dosage tested is varies from 50 mg/L to 1500 mg/L. Since the concentration for ferrous sulphate is not as much as alum (149879 mg/L = 15%), the volume needed is much more which is from 0.3 mL to 10 mL respectively. The result for sludge settling then is shown below in Figure 4.3.

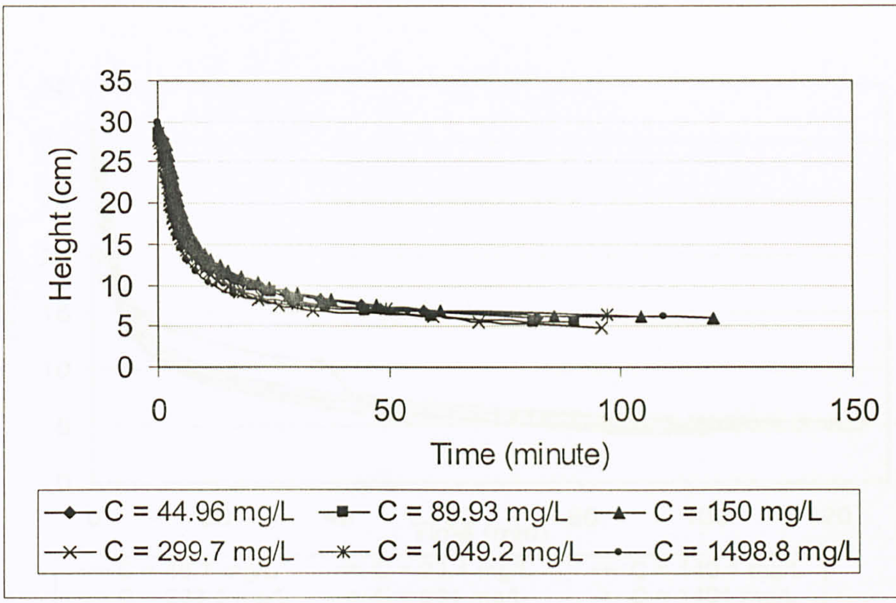

Figure 4.3: Graph of Height versus Time of Ferrous Sulphate with Different Dosage

All sample showed the same shape of line as alum. From the graph, it showed that the highest gradient for sludge settleability using ferrous sulphate was 3.75 cm/min on Sample 6 which used 1498.8 mg/L dosage of ferrous sulphate. Other sample settleability result varies from 2.15 cm/min to 3.17 cm/min as shown in Appendix B4.

4.1.2.3 Settleability Results using Ferric Chloride as a Coagulant

In ferric chloride analysis, dosage tested is varies from 46.7 mg/L to 1401 mg/L. Since the concentration for ferrous sulphate is low (46705 mg/L = 4.6%), the volume needed is much more which is from 1 mL to 30 mL respectively. The result for sludge settling then is shown below in Figure 4.4.

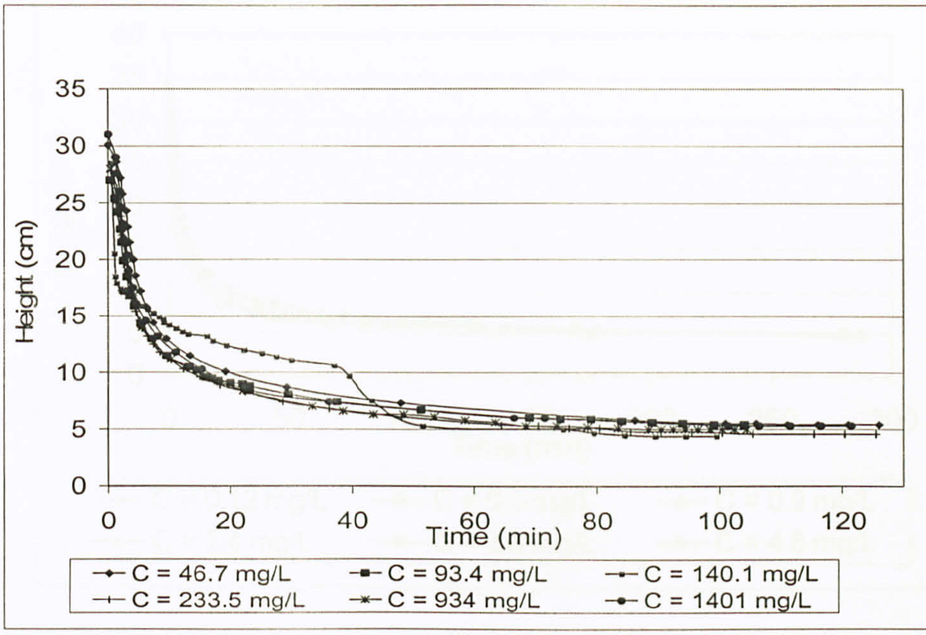

Figure 4.4: Graph of Height versus Time of Ferric Chloride with Different Dosage

From the graph, Sample 3 which used 140.1 mg/L showed an edges line shape unlike other samples. It is not acceptable and happened maybe due to some error occurred during the settleability reading. However, the highest gradient for sludge settleability using ferric chloride was on Sample 6 which used 1401 mg/L dosage of ferric chloride with the settleability gradient of 3.875 cm/min. Other samples recorded the settleability gradient between 0.45 cm/min to 3.11 cm/min as shown in Appendix B5.

4.1.2.4 Settleability Result using RFS as a Coagulant

In RFS analysis, dosage tested is varies from 0.12 mg/L to 4.8 mg/L. Since the concentration for RFS is much lower (600 mg/L = 0.06 %), the volume needed for the dosage was from 0.2 mL to 8 mL respectively. The result for sludge settling then is shown below in Figure 4.5.

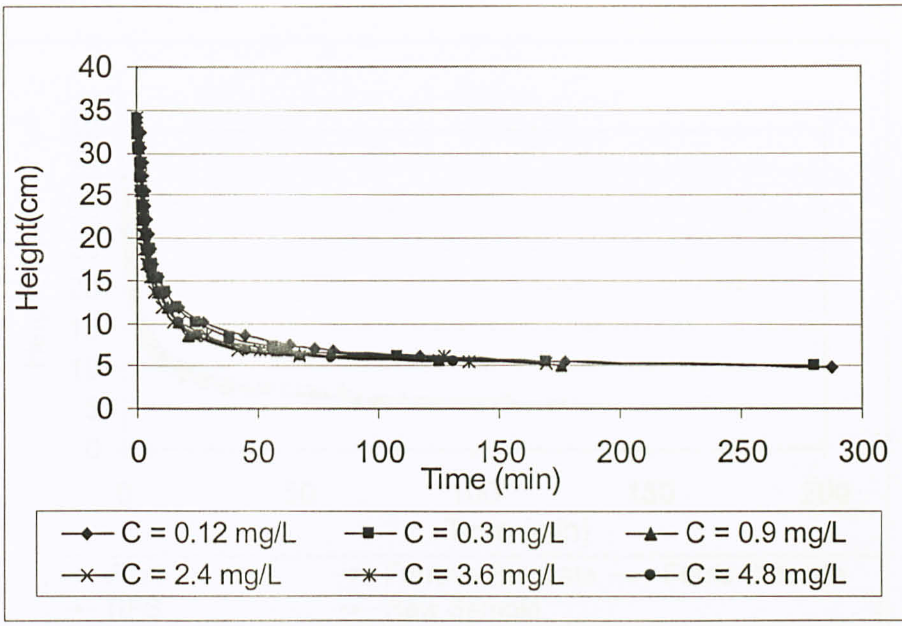

Figure 4.5: Graph of Height versus Time with Different Dosage of RFS

All samples of RFS are acceptable and showed high slope of settleability compared to other type of coagulants. From the graph line calculation, it showed that the highest gradient for sludge settleability using RFS was 5.15 cm/min on Sample 3 which used 0.9 mg/L dosage of RFS. Other samples recorded the settleability gradient between 3.09 cm/min to 4.86 cm/min as shown in Appendix B6.

4.1.2.5 Settleability Comparison for Each Coagulant

The best settleability for each coagulant is tabulated in Figure 4.6. Sludge raw sample settleability also included to indicate the performance after coagulant applied. By comparison, the best coagulant for sludge settleability is RFS which resulted settling rate 5.15 cm/min and performance increased by 115%.

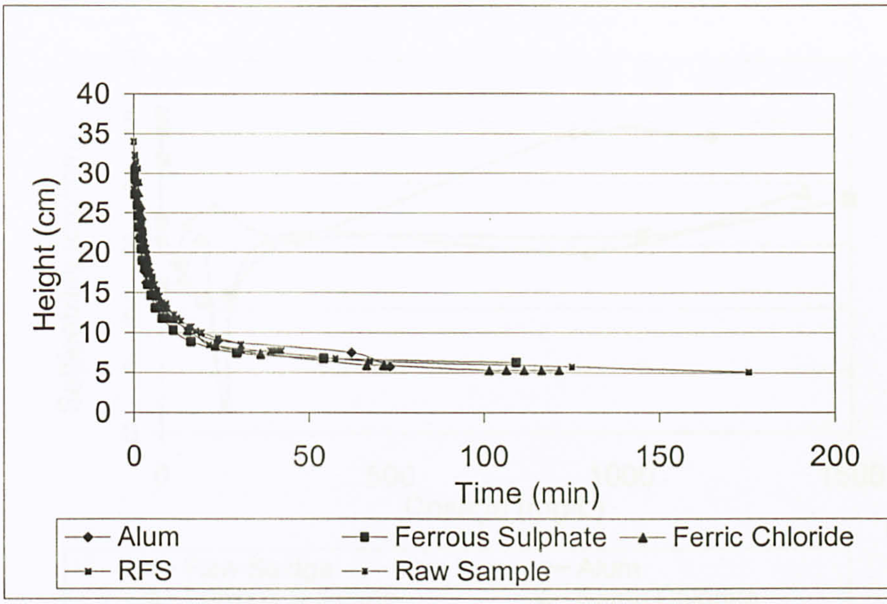

Figure 4.6: Graph of Best Settleability between Coagulants and Raw Sample

RFS also needed an extremely small amount of dosage if compared to other coagulants as well. RFS used only 0.9 mg/L for settling rate 5.15 cm/min while alum used 900 mg/L for 4.8 cm/min, $FeSO_4$ used 1500 mg/L for 3.75 cm/min, and $FeCl_3$ used 1400 mg/L for 3.875 cm/min. Figure 4.7 and 4.8 below show the graph of settleability with respect to dosage for each coagulant and tabulated in the Table 4.1 below. From statistical data, at 5% level of significant, RFS is a significant coagulant in improving the groundwater sludge settleability from initial. (Appendix B7)

Table 4.1: Best Settleability Summary

Coagulants	Dosage (mg/l)	Settling Rate (cm/min)	Efficiency (%)
None (Raw)	-	2.4	-
Alum	900	4.8	100
Ferrous Sulphate	1500	3.75	56
Ferric Chloride	1401	3.875	62
RFS	0.90	5.15	115

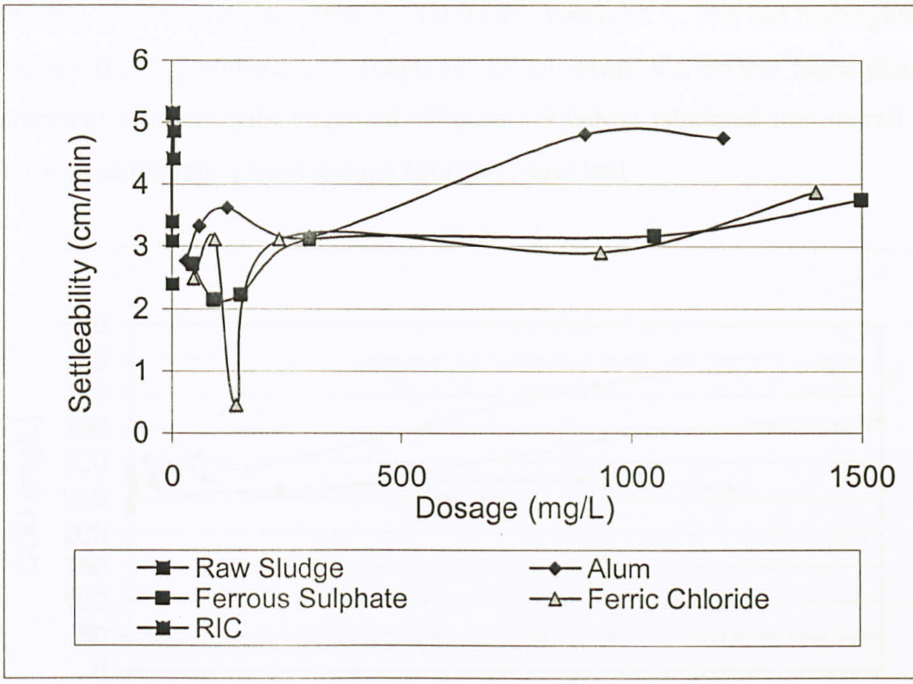

Figure 4.7: Graph of Best Settleability versus Dosage for All Coagulants

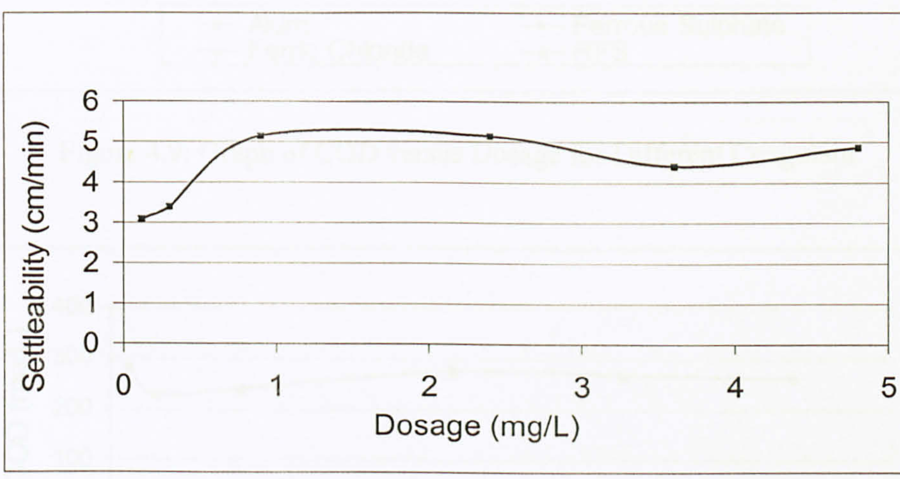

Figure 4.8: Graph of RFS Settleability

4.1.3 COD Result for Municipal Sludge Treatment

Apart from settling rate measurement, the study also included the effect of RFS to the COD, Colour, Turbidity, as well as TSS removal of the sewage sludge. Appendix C1 indicated the results of all samples for raw sewage sludge before and after the addition of coagulant with their respective dosages including the settleability gradient results. In those tables in Appendix C, the red highlighted the raw sludge reading without any coagulant effect while the yellow highlighted the improvement after coagulant applied. Figure 4.9 below tabulated the overall result for COD measurement versus dosage for each coagulant.

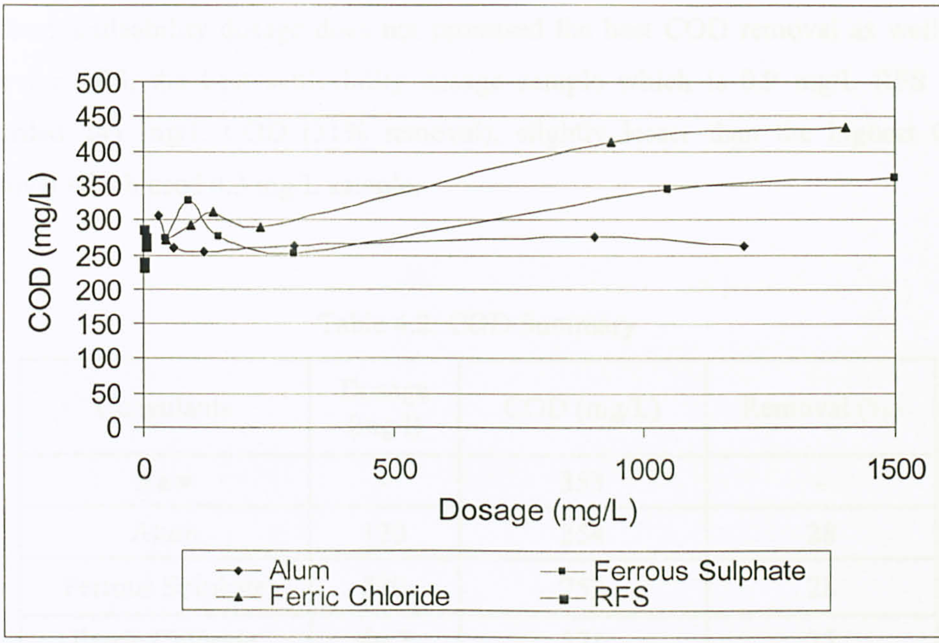

Figure 4.9: Graph of COD versus Dosage for Different Coagulant

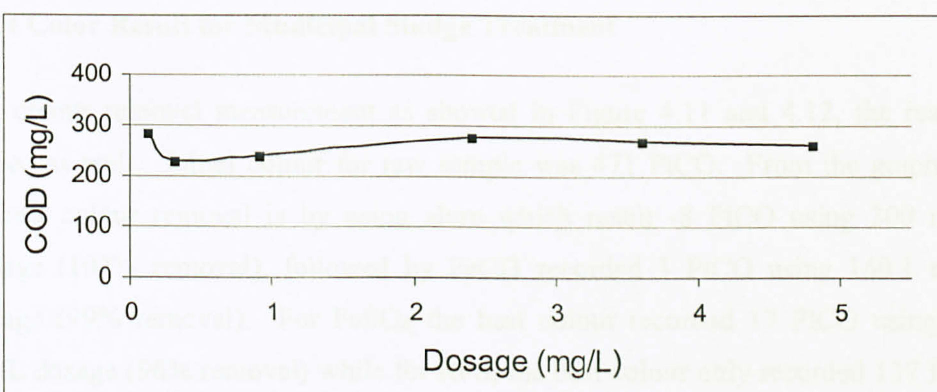

Figure 4.10: Graph of COD versus Dosage for RFS only

For COD removal measurement, all samples of coagulant gave different amount with subject to the dosage. Initially, COD for raw sample was 353 mg/L. From the graph, the highest COD removal is using RFS which result 231 mg/L COD using 0.3

mg/L sample (about 35% removal). At the other hand, alum highest recorded 254 mg/L COD using 120 mg/L (28% removal), $FeSO_4$ highest recorded 252 mg/L COD using 299.7 mg/L sample (28% removal), while $FeCl_3$ highest recorded 271 mg/L COD using 46.7 mg/L (23% removal). In this case, RFS proved to be better coagulant aid for COD with low dosage required. However, from the overall result, the best settleability dosage does not promised the best COD removal as well. In case for RFS, the best settleability dosage sample which is 0.9 mg/L RFS only recorded 241 mg/L COD (31% removal), slightly lesser than the highest COD removal which used 0.3 mg/L sample.

Table 4.2: COD Summary

Coagulants	Dosage (mg/l)	COD (mg/L)	Removal (%)
Raw	-	353	-
Alum	120	254	28
Ferrous Sulphate	300	252	28
Ferric Chloride	46.7	271	23
RFS	0.30	231	35

4.1.4 Color Result for Municipal Sludge Treatment

For colour removal measurement as showed in Figure 4.11 and 4.12, the reading varied as well. Initial colour for raw sample was 471 PtCO. From the graph, the highest colour removal is by using alum which result -8 PtCO using 300 mg/L dosage (102% removal), followed by FeCl3 recorded 3 PtCO using 140.1 mg/L dosage (99% removal). For $FeSO_4$, the best colour recorded 17 PtCO using 150 mg/L dosage (96% removal) while for RFS, the best colour only recorded 137 PtCO using 3.6 mg/L dosage (71% removal). For RFS best settleability dosage (0.9 mg/L), the colour recorded only 162 PtCO (66% removal). The result concluded that RFS is not the best coagulant as alum and other coagulant for colour removal even though it is best for settleability improvement.

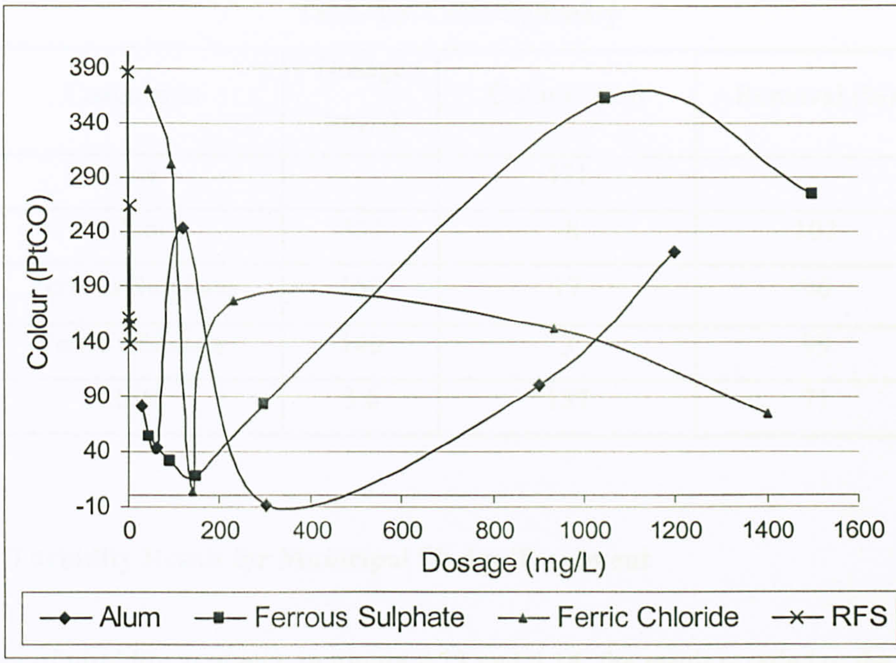

Figure 4.11: Graph of Colour versus Dosage for Different Coagulant

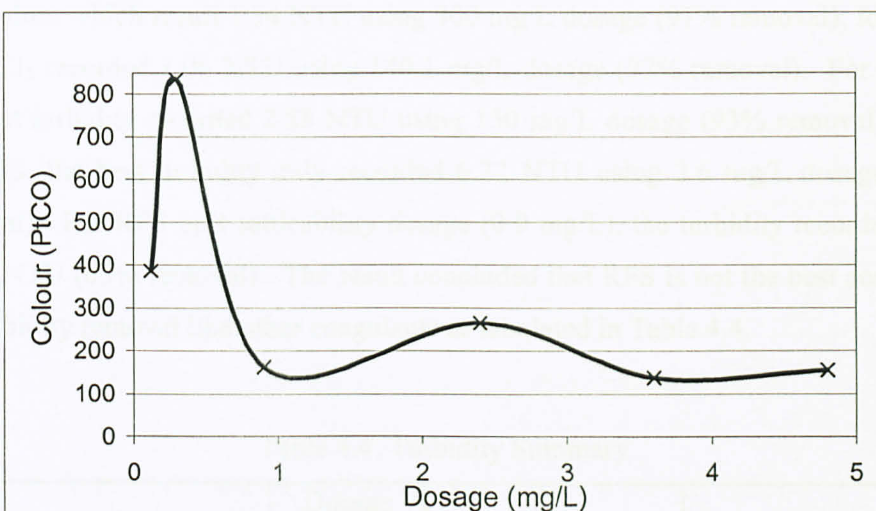

Figure 4.12: Graph of Colour versus Dosage for RFS

Table 4.3: Color Summary

Coagulants	Dosage (mg/l)	Color (PtCo)	Removal (%)
Raw	-	471	-
Alum	300	-8	102
Ferrous Sulphate	150	17	96
Ferric Chloride	140	3	99
RFS	3.6	137	71

4.1.5 Turbidity Result for Municipal Sludge Treatment

In case of turbidity as shown in Figure 4.13 and 4.14, the result is tailed to the colour result. If the colour result is high, the turbidity also went high. Initial turbidity of raw sludge supernatant is 39 NTU. Similar to colour, highest turbidity removal is by using alum which result 1.34 NTU using 300 mg/L dosage (97% removal), followed by $FeCl_3$ recorded 1.06 NTU using 140.1 mg/L dosage (97% removal). For $FeSO_4$, the best turbidity recorded 2.88 NTU using 150 mg/L dosage (93% removal) while for RFS, the best turbidity only recorded 6.22 NTU using 3.6 mg/L dosage (84% removal). For RFS best settleability dosage (0.9 mg/L), the turbidity recorded only 13.57 NTU (65% removal). The result concluded that RFS is not the best coagulant for turbidity removal like other coagulants as tabulated in Table 4.4.

Table 4.4: Turbidity Summary

Coagulants	Dosage (mg/l)	Turbidity (NTU)	Removal (%)
Raw	-	39	-
Alum	300	1.34	97
Ferrous Sulphate	150	2.88	93
Ferric Chloride	140	1.06	97
RFS	3.6	6.22	84

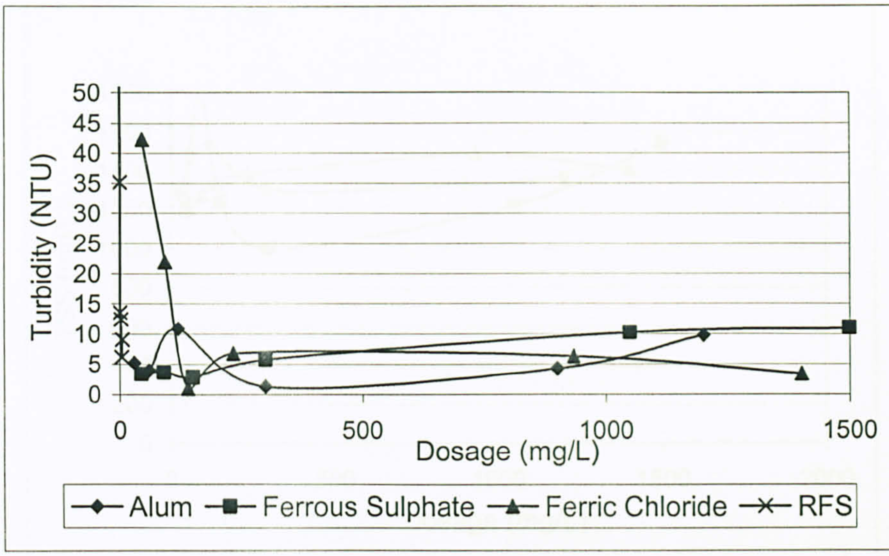

Figure 4.13: Graph of Turbidity versus Dosage for Different Coagulant

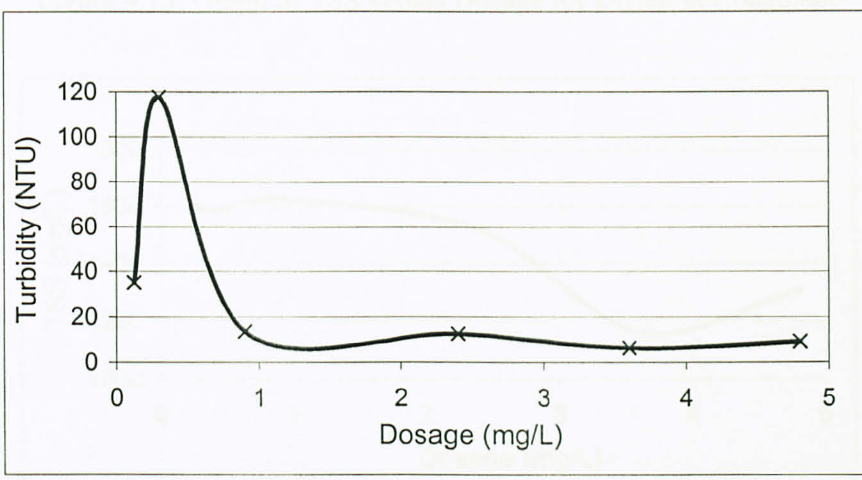

Figure 4.14: Graph of Turbidity versus Dosage for RFS

4.1.6 TSS Result for Municipal Sludge Treatment

In TSS experiment as shown in Figure 4.15 and 4.16, the raw sample of sludge recorded 1252 mg/L. Unfortunately, after coagulant is added, almost all samples result increased the TSS value except for three samples; 300 mg/L alum that recorded 1001 mg/L TSS (20% removal), 1049 mg/L alum that recorded 1220 mg/L TSS (3 % removal), and 3.6 mg/L RFS that recorded 1162 mg/L TSS (7% removal). As a result, it can be summarized that all samples of coagulants in this experiment is not effective in removing TSS of the sewage sludge.

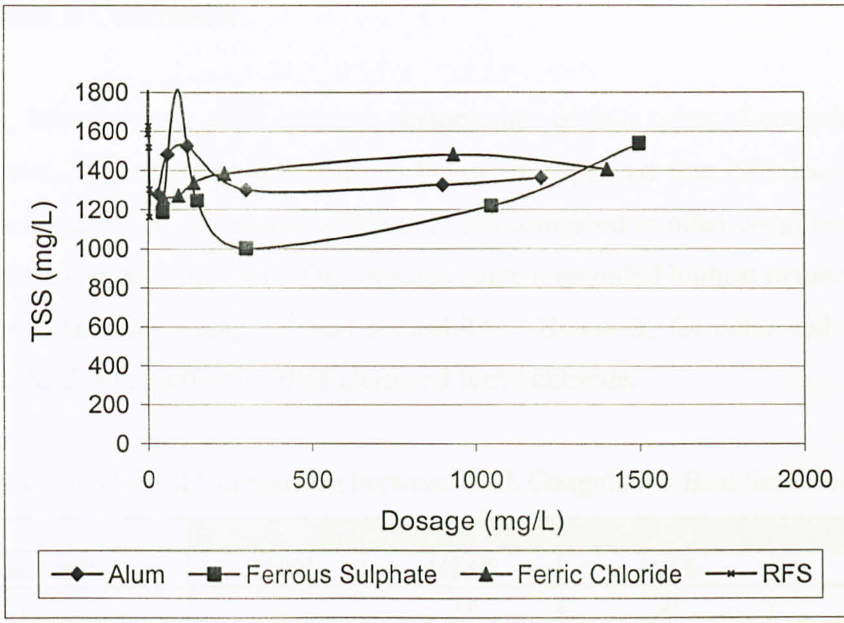

Figure 4.15: Graph of TSS versus Dosage for Different Coagulant

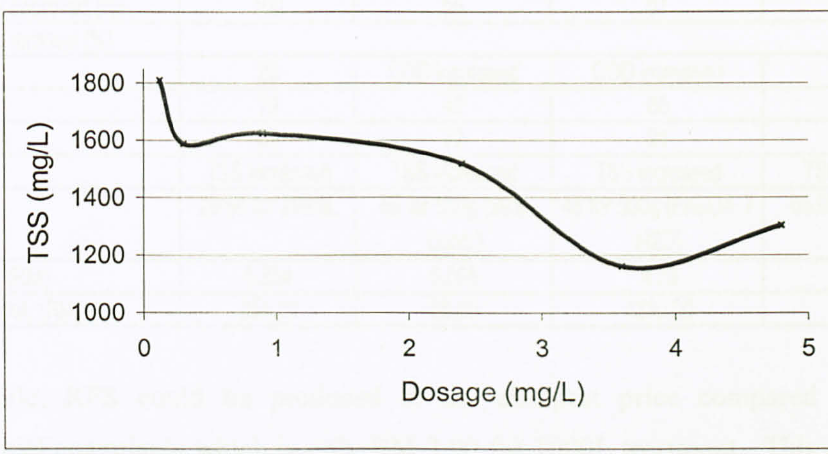

Figure 4.16: Graph of TSS versus Dosage for RFS

Table 4.5: TSS Summary

Coagulants	Dosage (mg/l)	TSS (mg/L)	Removal (%)
Raw	-	1252	-
Alum	300	1001	20
Ferrous Sulphate	-	-	TSS increased
Ferric Chloride	-	-	TSS increased
RFS	3.6	1162	7

4.1.7 Phase I: Conclusion

By then, from research point of view, performance of four types of coagulants was investigated. By referring to Table 4.6 below, it is proved that RFS has a higher sludge settleability improvement which is 115% compared to other coagulants. RFS also better coagulants aids for COD removal since it recorded highest removal which is 31% for the same dosage of best settleability. However, for color and turbidity removal, RFS is less effective than alum and ferric chloride.

Table 4.6: Overall Comparison between Each Coagulant's Best Settleability

Coagulant	Alum	Ferrous Sulphate	Ferric Chloride	RFS
Concentration (mg/L)	300 000	149 879	46 705	600
Volume (mL)	3	10	30	1.5
Dosage (mg/L)	900.00	1498.80	1401.00	0.90
Dosage for 1000L (mg)	900000	1498800	1401000	900
Settleability gradient (cm/min)	4.800	3.750	3.875	5.150
Settleability Improved (%)	100	56	61	115
Percentage removal (%)				
COD	22	COD increased	COD increased	32
Colour	79	42	85	66
Turbidity	89	72	91	65
TSS	TSS increased	TSS increased	TSS increased	TSS increased
Cost (RM)	29.50 for 250mL	55 for 500g (99% Conc.)	45 for 500g (FeSO4. 7 H2O)	65.00 for 2500mL H2SO4
Cost for 1L (RM)	0.354	0.068	4.23	0.0039
Cost for 1000L (RM)	354.00	68.00	4230.00	3.90

Meanwhile, RFS could be produced at the cheapest price compared to other commercial coagulants which is only RM 3.90 for 1000L treatment. This condition is merely because the reused of sludge that free of charge. Therefore, further research and analysis need to be done to ensure the practicality of RFS as an alternative of coagulant in improving the thickening process.

4.2 Phase II: Leachate Treatment Using RFS

4.2.1 Groundwater Sludge Digestion

In the second phase of project, the sludge was digested again for leachate treatment purposes. This time, the optimum time of the sludge digestion is being analysed. The weight used for sludge is 10 g with 100 mL distilled water. From the experiment done, the optimum time for sludge digestion using acid sulphuric is 4 hour. The highest amount of Fe^{2+} concentration digested is 680 mg/L and showed in the Figure 4.17 below.

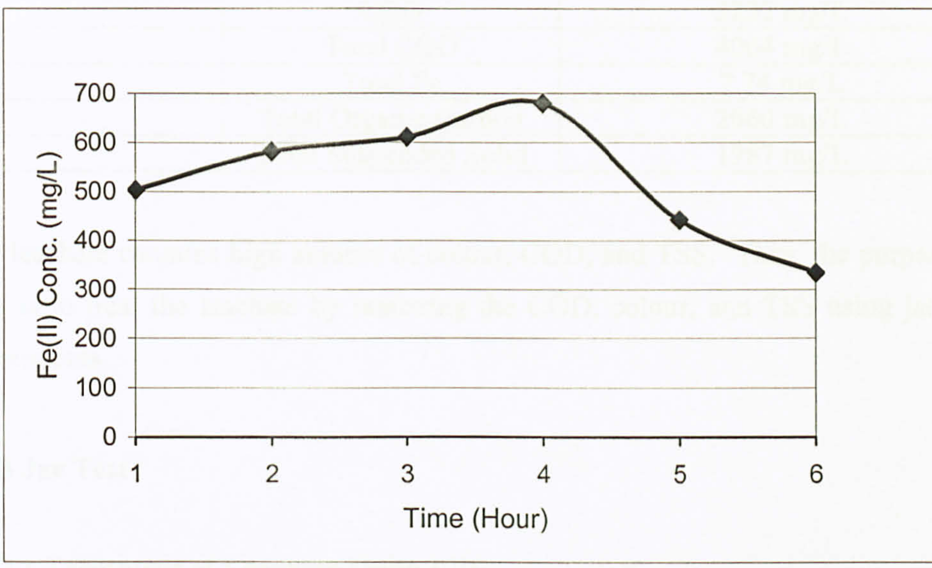

Figure 4.17: Graph of Iron Fe (II) Concentration versus Time

Then, the RFS is produced using the optimum dosage of 50 mL and optimum time of 4 hour. The final result of Fe^{2+} concentration from that RFS is 350 mg/L. The amount is considered low since the expected result should be 100000 mg/L. However, the total Fe concentration from that RFS is about 80000 mg/L. The result concluded that the ion Fe^{2+} is not fully digested instead, the RFS is rich with iron Fe^{3+} (Appendix A4).

4.2.2 Leachate Raw Data

Leachate collected from Pulau Burung, Penang has been investigated in the study for second phase project. Several parameters has been analysed from the raw and soluble of leachate which is total COD, soluble COD, colour, Total Organic Carbon, and Total Fe concentration. The results are tabulated in the table below.

Table 4.7: Leachate Characteristics

Leachate Stage	Parameter	Reading
Raw	Colour	3771 PtCo
	COD	3232 mg/L
	Total COD	4004 mg/L
	Total Fe	7.74 mg/L
	Total Organic Carbon	2060 mg/L
	Total Suspended Solid	1987 mg/L

The leachate contains high amount of colour, COD, and TSS. Thus, the purpose of RFS is to treat the leachate by removing the COD, colour, and TSS using jar test experiments.

4.2.3 Jar Test

4.2.3.1 Treatment of Leachate Using RFS

Raw sample of leachate is treated using RFS without any pH adjustment. The only data that varied is the dosage of the RFS used which is ranging from 160 mg/L to 8000 mg/L. Since the concentration of RFS is 8% (80000 mg/L), the volume is varied from 2 mL to 100 mL. Initial pH is constant for all beakers which is 8.50. After treatment, the pH of each beaker became acidic subject to RFS concentration (Appendix D1). The higher concentration of RFS, the lower final pH value of the leachate. The final pH is varied from 8.12 to 2.16. The total COD, TSS and color is measured from the treated leachate. The result is showed in Figure 4.18.

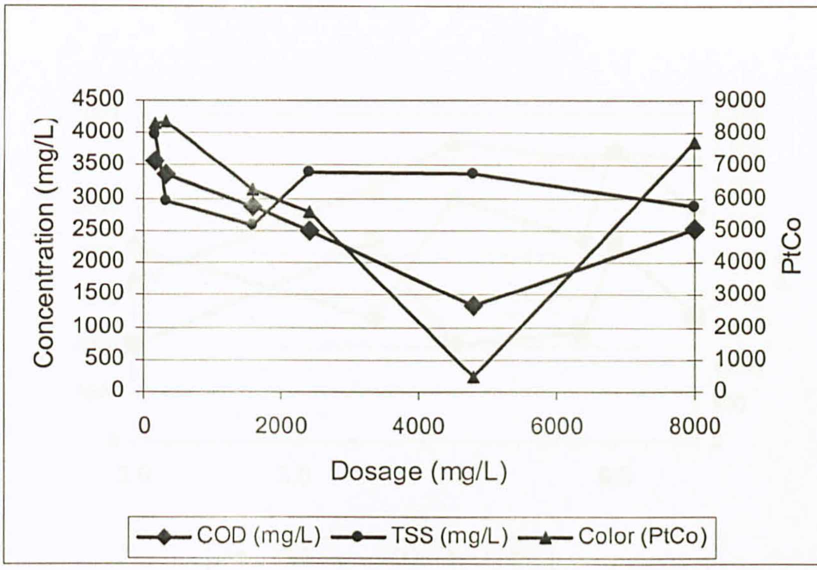

Figure 4.18: Treatment of Raw Leachate using RFS

The results proved that COD and color is removed when used an RFS concentration of 4800 mg/L. Final COD is 1324 mg/L (67% removal) while final color is 438 PtCo (88% removal). As for TSS, the result, 2589 mg/L, increased from initial raw value. Hence, RFS is effective in remove COD and color in the raw leachate.

4.2.3.2 Determination of Optimum pH using RFS

The next jar test is to determine the optimum pH for RFS. Even though RFS is effective without any pH adjustment, the experiment is conducted to detect whether the efficiency is improve when adjusting the pH of leachate within the range from 3 to 10. The dosage for RFS is constant for all beakers. Since the concentration of RFS is 80000 mg/L, the volume used is 10 mL each beaker which the dosage is about 800 mg/L. The result of Colour, COD, and TSS was measured to determine the performance of RFS after being applied to the leachate. From the experiment, it is observed that the optimum pH is 6 for highest colour removal. However, for COD and TSS, no significant removal was detected.

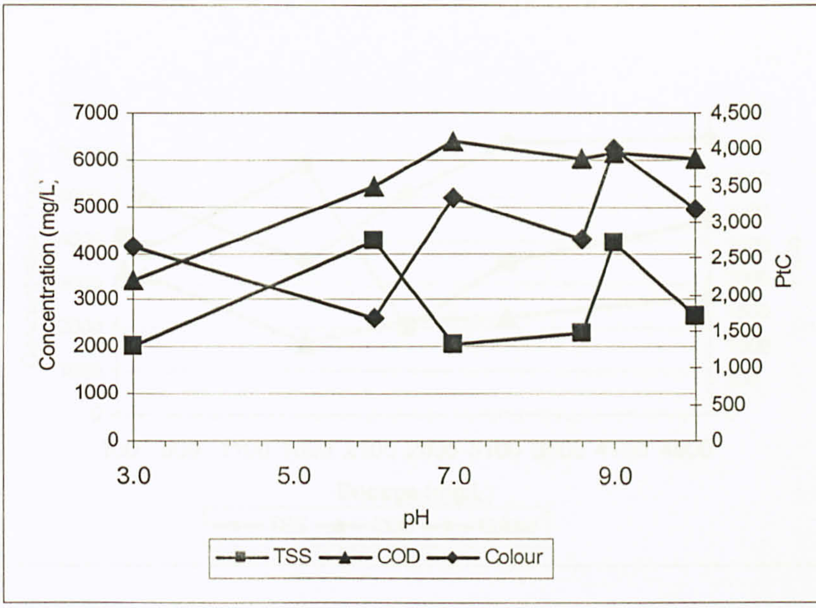

Figure 4.19: Treatment of Raw Leachate using RFS (pH 3 to pH 10)

From Figure 4.19, the highest color being removed is at pH 6 which the result is 1670 PtCo (56% removal). The least color removed is at pH 9 which is about 4000 PtCo. For TSS and COD, there is no removal at all but instead, the value is increasing from the initial raw value. Thus, pH 6 is only applicable to remove color in the leachate.

4.2.3.3 Determination of Optimum Dosage using RFS

Once the optimum pH is obtained, the jar test was conducted to determine the optimum dosage for the respective pH. From part 4.2.3.2, the optimum pH of 6 is taken when the result of highest color of leachate is removed. The dosage was varied from the range of 160 mg/L to 4800 mg/L to detect the most significant impact. From Figure 4.20, the result showed that at pH 6, RFS effective in remove COD and color. The final COD is 1668 mg/L (58% removal) while the final color is 2259 PtCo (40% removal), both used 1600 mg/L RFS. However, the TSS result was increased. Thus, RFS still effective in remove COD and color but the percentage is decreased compared to without adjusting pH.

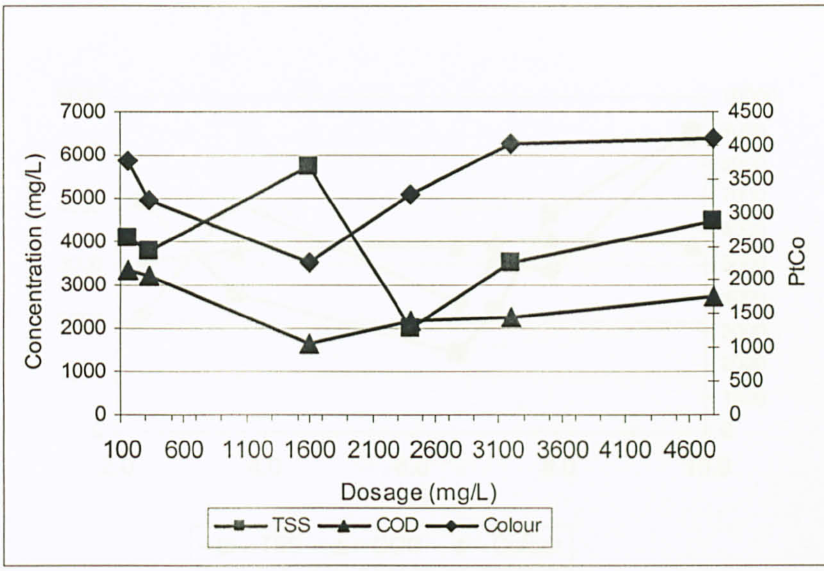

Figure 4.20: Treatment of Raw Leachate using RFS (At Optimum pH=6)

4.2.3.4 Determination of Optimum pH using Alum

Other than RFS, commercial coagulant also used in the leachate treatment. Alum is one of the coagulants analyzed in this project. As RFS, jar test using alum considered the effect of pH. Thus, optimum pH for leachate when using alum is investigated within the range from 3 to 10. Concentration of alum is 30% (300 000 mg/L). Since the effect of pH is varied, the dosage for all beakers is equal which is 600 mg/L. The result of Colour, COD, and TSS measured to determine the performance of alum after being applied to the leachate. The result is showed in Figure 4.21. From the graph, it is observed that no significant removal for COD and color from the initial raw leachate. However, alum is effective in remove TSS when the result is 1408 mg/L (29% removal) occurred at the pH 6.

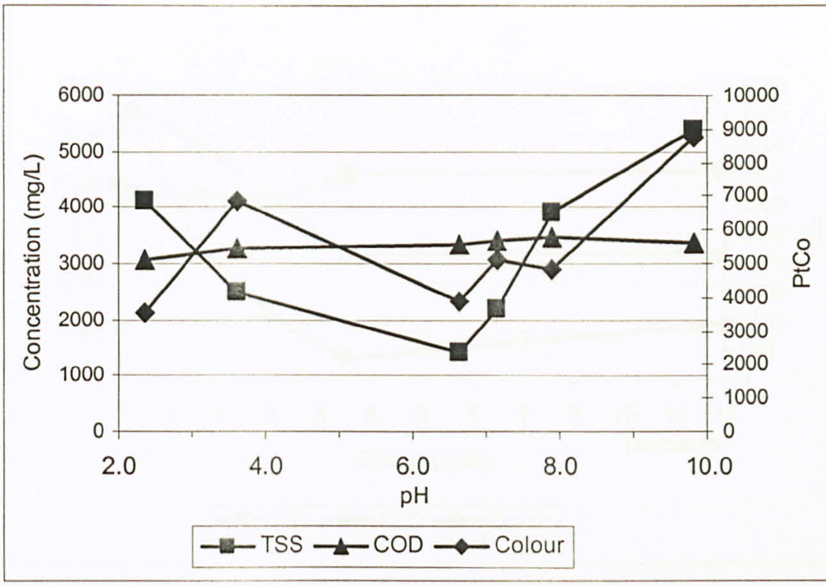

Figure 4.21: Treatment of Raw Leachate using Alum (pH 2 to pH 10)

4.2.3.5 Determination of Optimum Dosage using Alum

Optimum dosage for alum in leachate treatment was investigated once the optimum pH is determined. From part 4.2.3.4, the optimum pH of 6 is taken when the result of highest TSS of leachate is removed. The dosage varied from the range of 30 mg/L to 12000 mg/L. From Figure 4.22, the result showed that at pH 6, RFS effective in remove COD and color. The final COD is 2576 mg/L (36% removal) while the final color is 370 PtCo (90% removal), both used 4500 mg/L RFS. However, the TSS result is increased, contrary with the result in previous part. Overall, alum is the most effective in removed color so far when the efficiency is 90%.

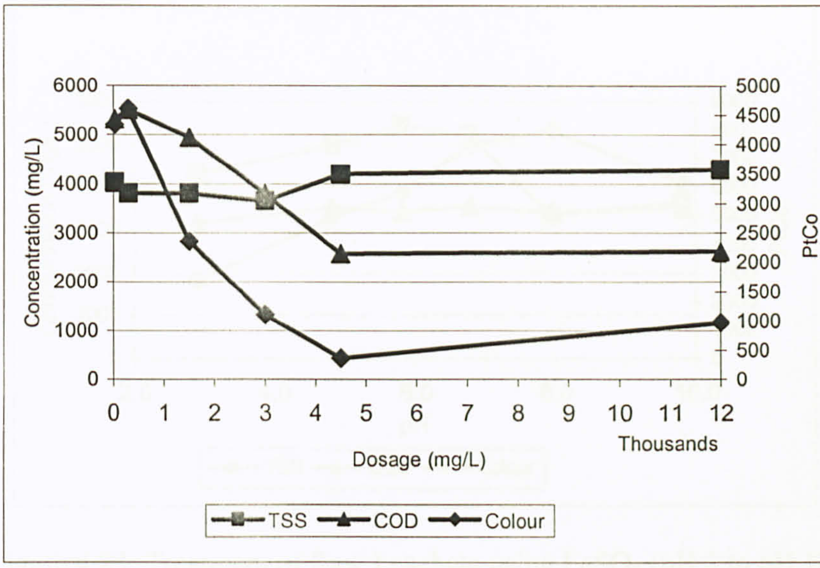

Figure 4.22: Treatment of Raw Leachate using Alum (At Optimum pH=6)

4.2.3.6 Determination of Optimum pH using $FeSO_4$

Other commercial coagulant investigated is $FeSO_4$. Like all, the effect of pH for $FeSO_4$ is determined using jar test within the range of 3 to 10. The concentration of $FeSO_4$ used is 3% (30000 mg/L). Since the pH is varied, the dosage is fixed which is 30 mg/L. The result of COD, color and TSS then showed in Figure 4.23. No significant value of COD and TSS has been removed from the experiment but for color, the final result is 2745 PtCo (27% removal) when pH is 3. The data obtained from this experiment showed that $FeSO_4$ is not effective in treating leachate compared to alum and RFS previously.

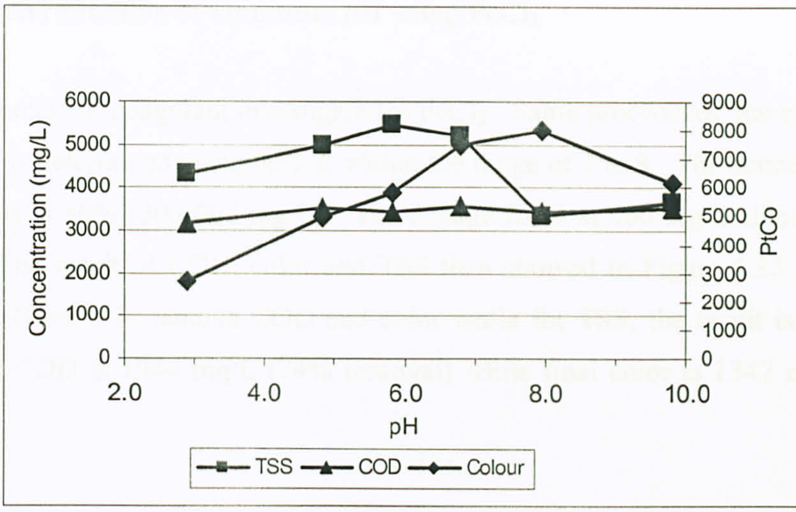

Figure 4.23: Treatment of Raw Leachate using $FeSO_4$ (pH 3 to pH 10)

4.2.3.7 Determination of Optimum Dosage using $FeSO_4$

The next experiment of jar test is to investigate the optimum dosage of treating leachate using $FeSO_4$. Even though the optimum pH obtained from Part 4.2.3.6 is 3 for color removal, the pH being analyzed here is 6 since from the literature review, iron coagulant is effective within the range of 5 to 11 while for $FeSO_4$, the range is from 4 to 8. The dosage used is varied from 60 mg/L to 6000 mg/L. From the result as showed in Figure 4.24, the final COD, color, and TSS increased from the raw value. Hence, for this experiment, $FeSO_4$ is not effective at all in treating leachate.

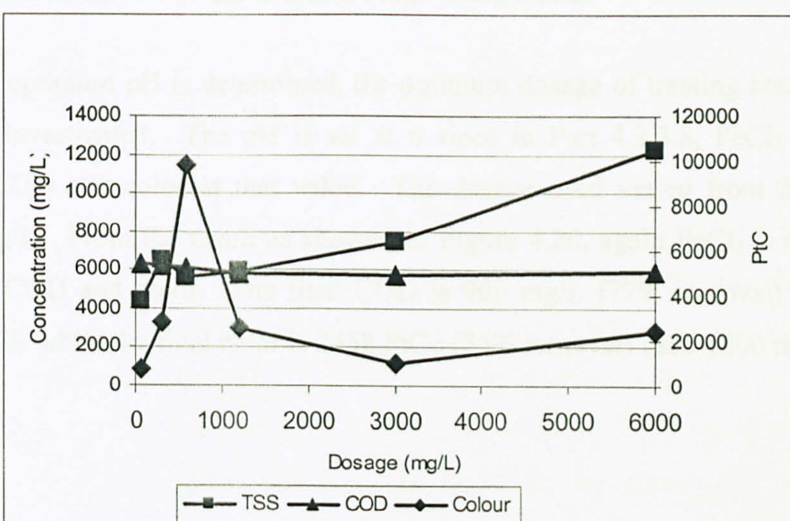

Figure 4.24: Treatment of Raw Leachate using $FeSO_4$ (At pH=6)

4.2.3.8 Determination of Optimum pH using $FeCl_3$

Final commercial coagulant investigated is $FeCl_3$. Same procedures, the effect of pH for $FeCl_3$ is determined using jar test within the range of 2 to 8. The concentration of $FeCl_3$ used is 30% (300 000 mg/L). The dosage fixed at 600 mg/L since the pH is varied. The result of COD, color and TSS then showed in Figure 4.25. At pH 6, $FeCl_3$ is effective in remove COD and color while for TSS, the result is increased. The final COD is 1044 mg/L (74% removal) while final color is 1347 mg/L (64% removal).

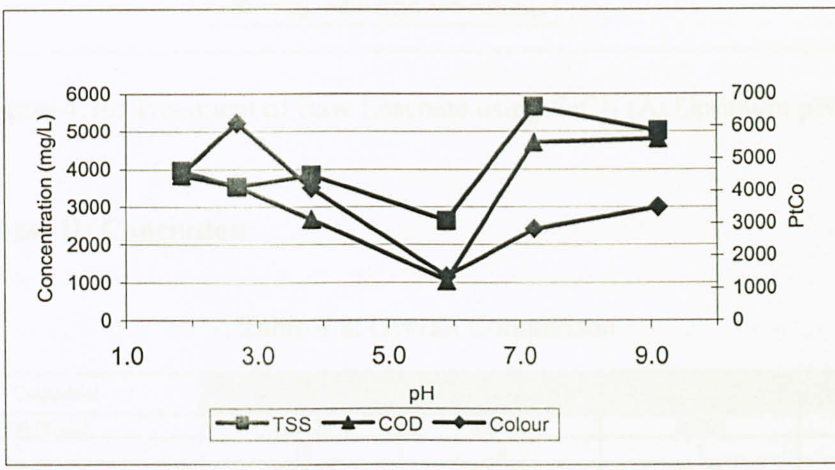

Figure 4.25: Treatment of Raw Leachate using $FeCl_3$ (pH 2 to pH 9)

4.2.3.9 Determination of Optimum Dosage using $FeCl_3$

Once the optimum pH is determined, the optimum dosage of treating leachate using $FeCl_3$ is investigated. The pH is set at 6 since in Part 4.2.3.8, $FeCl_3$ effectively remove COD and color at that value. The dosage used varied from 30 mg/L to 12000 mg/L. From the result as showed in Figure 4.26, again $FeCl_3$ is effective in removed COD and color. The final COD is 909 mg/L (77% removal) used 6000 mg/L $FeCl_3$ while the final color is 2458 PtCo (35% removal) used 1800 mg/L $FeCl_3$.

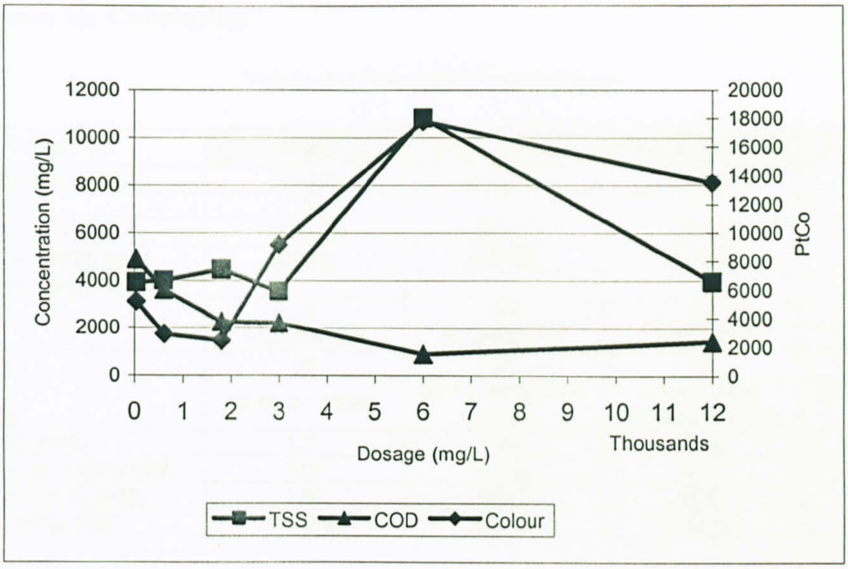

Figure 4.26: Treatment of Raw Leachate using $FeCl_3$ (At Optimum pH=6)

4.2.4 Phase II: Conclusion

Table 4.8: Overall Comparison

Coagulant	Alum	Ferric Chloride	Ferrous Sulphate	RFS
Concentration (mg/L)	300000	300000	30000	8000
Volume (mL)	15	2	1	60
Dosage (mg/L)	4500.00	600.00	30.00	4800.00
Dosage for 1000L (mg)	900000	600000	30000	4800000
Percentage removal (%)				
COD	36	74	20	67
TSS	INCREASED	INCREASED	INCREASED	INCREASED
Colour	90	64	27	88
Cost (RM)	29.50 for 250mL	55 for 500g (99% Conc.)	45 for 500g (FeSO4. 7 H2O)	65.00 for 2500mL H2SO4
Cost for 1L (RM)	1.77	0.44	0.18	0.52
pH Adjustment Cost (RM)	0.05	0.136	0.11	None
Total Cost for 1L (RM)	1.82	0.576	0.29	0.52
Cost for 1000L (RM)	1820.00	576.00	290.00	520.00

Best performances for all coagulants are tabulated in Table 4.8. For COD removal, $FeCl_3$ is the best coagulant since it can remove 74% used 600 mg/L dosage followed by RFS with 67% (4800 mg/L dosage), while alum and $FeSO_4$ are not really effective with 36% (4500 mg/L dosage) and 20% (30 mg/L dosage) respectively. For TSS, all coagulants showed increment in the results. However, for color, with the same dosage as COD, alum is the best coagulant since it can remove 90%, followed by RFS (88% removal), $FeCl_3$ (64% removal), and $FeSO_4$ (27% removal).

4.2.4 Phase II: Conclusion

Table 4.8: Overall Comparison

Coagulant	Alum	Ferric Chloride	Ferrous Sulphate	RFS
Concentration (mg/L)	300000	300000	30000	8000
Volume (mL)	15	2	1	60
Dosage (mg/L)	4500.00	600.00	30.00	4800.00
Dosage for 1000L (mg)	900000	600000	30000	4800000
Percentage removal (%)				
COD	36	74	20	67
TSS	INCREASED	INCREASED	INCREASED	INCREASED
Colour	90	64	27	88
Cost (RM)	29.50 for 250mL	55 for 500g (99% Conc.)	45 for 500g (FeSO4. 7 H2O)	65.00 for 2500mL H2SO4
Cost for 1L (RM)	1.77	0.44	0.18	0.52
pH Adjustment Cost (RM)	0.05	0.136	0.11	None
Total Cost for 1L (RM)	1.82	0.576	0.29	0.52
Cost for 1000L (RM)	1820.00	576.00	290.00	520.00

Best performances for all coagulants are tabulated in Table 4.3. For COD removal, $FeCl_3$ is the best coagulant since it can remove 74% used 600 mg/L dosage followed by RFS with 67% (4800 mg/L dosage), while alum and $FeSO_4$ are not really effective with 36% (4500 mg/L dosage) and 20% (30 mg/L dosage) respectively. For TSS, all coagulants showed increment in the results. However, for color, with the same dosage as COD, alum is the best coagulant since it can remove 90%, followed by RFS (88% removal), $FeCl_3$ (64% removal), and $FeSO_4$ (27% removal).

The results proved that RFS is effective and comparable with other commercial coagulants in leachate treatment. Moreover, in term of cost wise, proceeding with laboratory condition, RFS is the cheapest among all. To treat 1000L of leachate, cost for RFS is only RM 520 compared to $FeCl_3$ (RM 576) and alum (RM 1820). Though $FeSO_4$ only cost about RM 290, the efficiency is not too good as others.

CHAPTER 5.0

CONCLUSION AND RECOMMENDATION

Recycled Ferrous Sulphate (RFS) is evidently one of the alternative ways to treat the groundwater sludge and leachate as well. Instead dispose it to the landfill with possibility release contaminant to the environment or treat it with highly cost, the study proved that iron content from groundwater sludge can be recycled to produce RFS.

In the first phase, it is observed that the highest concentration for iron Fe^{2+} was 6394 mg/L when digested with 10 mL of sulphuric acid. Therefore, iron is confirmed could be extracted from groundwater sludge and possible to act as a commercial coagulant. RFS was observed to be most effective coagulant in increasing the settling rate of sewage sludge and hence, improved the sewage sludge thickening process. RFS recorded highest settling rate of 5.15 cm/min with 0.9 mg/L dosage (115% efficiency), while alum recorded 4.8 cm/min with 900 mg/L dosage (100% efficiency), $FeSO_4$ recorded 3.75 cm/min with 1500 mg/L dosage (56% efficiency), and $FeCl_3$ recorded 3.875 cm/min with 1400 mg/L (61% efficiency). RFS also better in COD removal which 32 % removal while alum recorded only 22 %.

In the second phase, RFS proved to be a reliable coagulant in leachate treatment. $FeCl_3$ recorded highest COD removal with result 1044 mg/L (74% efficiency), followed by RFS with 1324 mg/L (67% efficiency), alum 2576 mg/L (36% efficiency) and $FeSO_4$ 3187 mg/L (20% removal). All coagulants was not effective in remove TSS. However, for color, alum is the best coagulant since it recorded 370 PtCo (90% efficiency), trailed by RFS 438 PtCo (88% efficiency), $FeCl_3$ 1347 PtCo (64% efficiency) and $FeSO_4$ 2745 PtCo (27% efficiency).

As a result, it can be concluded that RFS plays a significant role in enhancing the thickening process and remove COD of sewage sludge. For leachate, RFS is comparable coagulant in remove COD and color. Presence of other metal constituents in sludge such as calcium oxide and silica oxide as well may have contributed towards both processes.

Since RFS extracted the iron from groundwater sludge, the production is much cheaper if compared to other commercial coagulant, thus there are prospect to further analyse the RFS to be commercialized as an alternative or replacement to current commercial coagulant.

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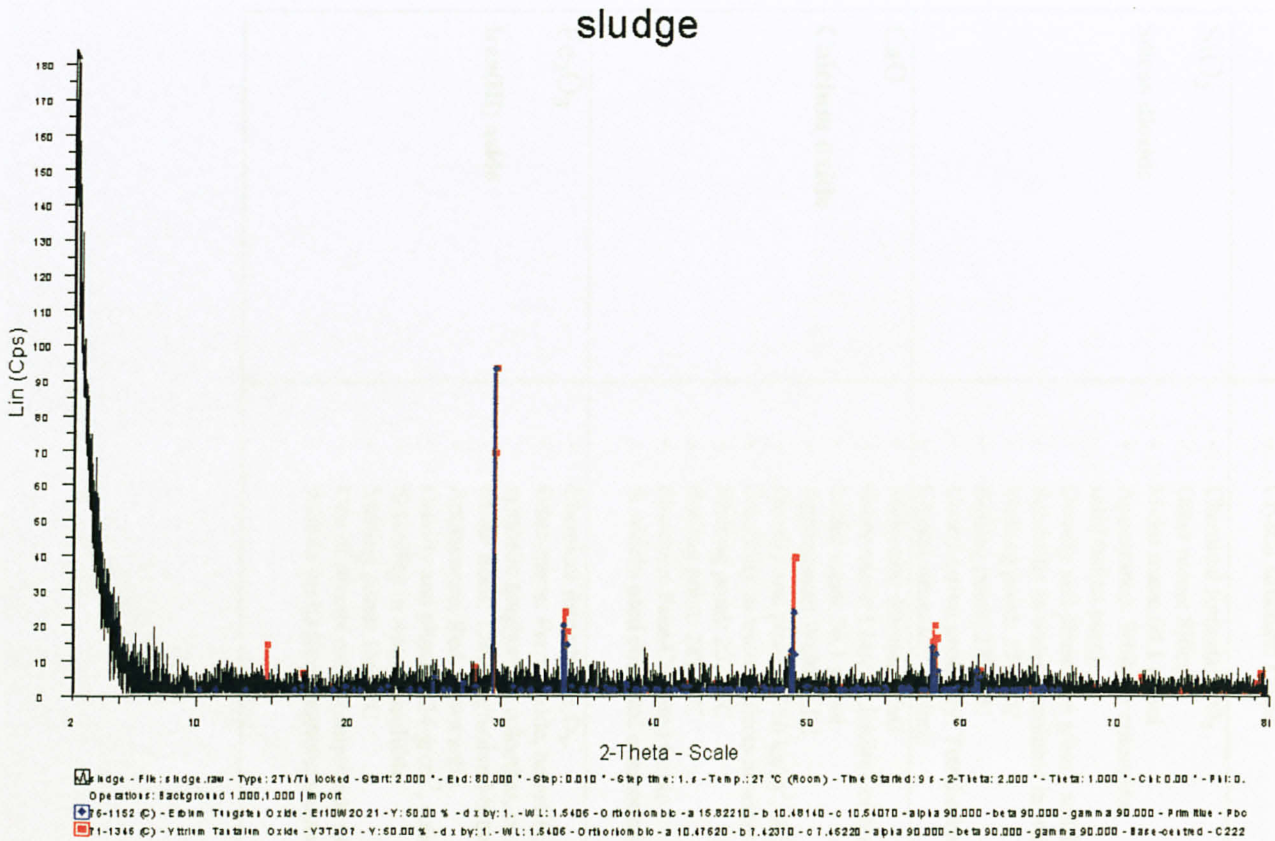
LIST OF APPENDICES

Appendix A1: XRD Result



Appendix A1 (con't)

Constituent Compound	Properties
Al_2O_3 **Aluminium oxide**	- Molecular formula: Al_2O_3 - Other name: Alumina, Aluminium(III) Oxide - Molar mass: 101.96 g/mol - Density and phase: 3.97 g/cm³, solid - Solubility in water in water: Insoluble. - Melting point: 2054°C - Boiling point: ~3000°C - Thermal Conductivity: 18 W/m·K - Coordination geometry: Octahedron. - Crystal structure: Cubic
SiO_2 **Silicon dioxide**	- Chemical formula: SiO_2 - Other name: Silica - Molar mass: 60.1 g/mol - Appearance: White or colourless solid (when pure) - Density and phase: 2.6 g/cm^3, solid - Solubility in water: Insoluble in water - Melting point: 1710 °C - Boiling point: 2230 °C - Coordination geometry: Tetrahedral - Crystal structure: Various
CaO **Calcium oxide**	- Molecular formula: CaO - Other name: Lime, quicklime or burnt lime. - Molar mass: 56.1 g/mol - Appearance: White solid - Density and phase: 3350 kg/m^3, solid - Solubility in water: Reacts in water - Melting point: 2572 °C - Boiling point: 2850 °C - Structure: Face-Centered Cubic - A widely used chemical compound
Fe_2O_3 **Iron(III) oxide**	- Chemical formula: Fe_2O_3. - Other name: Ferric oxide, hematite, red iron oxide, synthetic maghemite, colcothar, or simply rust - Molar mass: 159.69 g/mol red-brown solid - Appearance: Red-brown solid - Density and phase: 5.24 g/cm^3, solid - Solubility in water: Insoluble - Melting point: 1565 °C - One of several oxide compounds of iron, and is most notable for its ferromagnetic properties.

Appendix A2: XRF Result

Elements	Percentage (%)
CaO	30.4
Fe2O3	23.3
SiO2	11.5
Al2O3	4.6
P2O5	0.765
MgO	0.396
MnO	0.374
Re	0.2
BaO	0.138
K2O	0.0218
SrO	0.0196
Tb4O7	0.00439

Appendix A3: Table of Digested Iron Fe (II) According Dosage of H_2SO_4

Beaker	H2SO4 (mL)	Dilution	Fe2+ Reading using Spechtrophotometer (mg/L)			Exact Fe2+ Content (mg/L)			Average Digested Fe2+ (mg/L)
			1	2	3	1	2	3	
1	2	1 ; 400	2.31	2.34	2.34	926.31	938.34	938.34	934.330
2	4	1 ; 800	2.39	2.39	2.37	1914.39	1914.39	1898.37	1909.050
3	6	1 ; 1200	0.94	0.96	0.95	1128.94	1152.96	1140.95	1140.950
4	8	1 ; 1000	2.08	2.04	2.1	2082.08	2042.04	2102.1	2075.407
5	10	1 ; 2500	2.54	2.58	2.55	6352.54	6452.58	6377.55	6394.223
6	12	1 ; 3500	0.05	0.05	0.06	175.05	175.05	210.06	186.720
7	0	0	0	0	0	0	0	0	0

Appendix A4: Table of Digested Iron Fe^{2+} According Time

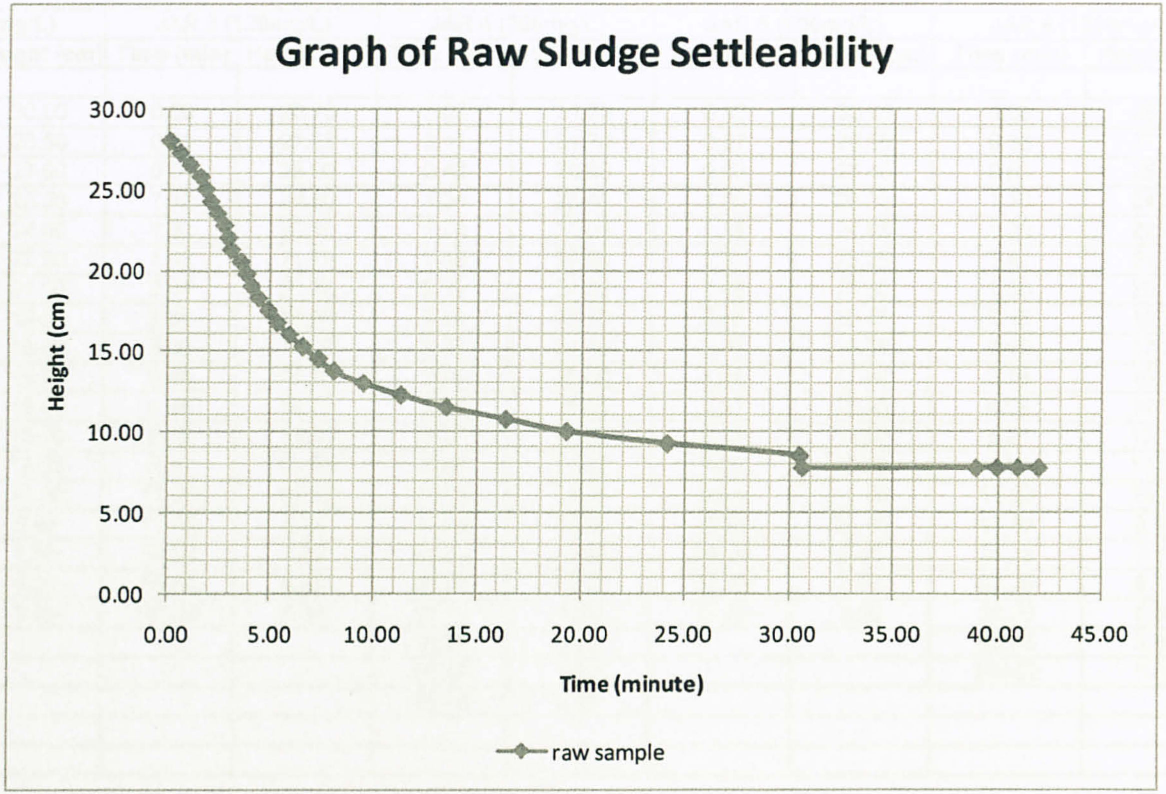
Beaker	H_2SO_4 (mL)	Dilution	Time (hour)	Fe^{2+} Reading using Spechtrophotometer (mg/L)			Exact Fe^{2+} Content (mg/L)			Average Digested Fe^{2+} (mg/L)
				1	2	3	1	2	3	
1	10	1 ; 250	1	0.9	1.96	2.05	225.9	491.96	514.55	503.255
2	10	1 ; 500	2	0.85	1.18	1.46	425.85	591.18	731.46	582.830
3	10	1 ; 500	3	1	1.58	1.08	501	791.58	541.08	611.220
4	10	1 ; 500	4	1.41	1.33	1.33	706.41	666.33	666.33	679.690
5	10	1 ; 500	5	0.84	0.95	0.86	420.84	475.95	430.86	442.550
6	10	1 ; 500	6	0.54	0.87	0.59	270.54	435.87	295.59	334.000

Appendix B1: Settleability Result

Sample	Coagulant	Dosage (mg/L)	Volume (ml)	Grad. (cm/min)
Raw	Nil	Nil	Nil	2.400
1-1	Alum	30	0.1	2.769
1-2	Alum	60	0.2	3.330
1-3	Alum	120	0.4	3.625
1-4	Alum	300	1	3.150
1-5	Alum	900	3	4.800
1-6	Alum	1200	4	4.750
2-1	Ferrous Sulphate	44.96	0.3	2.720
2-2	Ferrous Sulphate	89.93	0.6	2.150
2-3	Ferrous Sulphate	150	1	2.230
2-4	Ferrous Sulphate	299.7	2	3.110
2-5	Ferrous Sulphate	1049.2	7	3.170
2-6	Ferrous Sulphate	1498.8	10	3.750
3-1	Ferric Chloride	46.7	1	2.500
3-2	Ferric Chloride	93.4	2	3.110
3-3	Ferric Chloride	140.1	3	0.450
3-4	Ferric Chloride	233.5	5	3.110
3-5	Ferric Chloride	934	20	2.900
3-6	Ferric Chloride	1401	30	3.875
M-1	RIC ($FeSO_4$)	0.12	0.2	3.090
M-2	RIC ($FeSO_4$)	0.3	0.5	3.400
M-3	RIC ($FeSO_4$)	0.9	1.5	5.150
M-4	RIC ($FeSO_4$)	2.4	4	5.150
M-5	RIC ($FeSO_4$)	3.6	6	4.410
M-6	RIC ($FeSO_4$)	4.8	8	4.860

Appendix B2: Result for Raw Sludge Settleability

raw sample	
time (min)	height (cm)
0.00	28.00
0.50	27.25
1.00	26.50
1.50	25.75
1.75	25.00
2.00	24.25
2.33	23.50
2.67	22.75
2.87	22.00
3.00	21.25
3.47	20.50
3.75	19.75
4.00	19.00
4.35	18.25
4.83	17.50
5.25	16.75
5.85	16.00
6.50	15.25
7.25	14.50
8.00	13.75
9.43	13.00
11.25	12.25
13.45	11.50
16.33	10.75
19.25	10.00
24.13	9.25
30.50	8.50
30.63	7.75
39.00	7.75
40.00	7.75
41.00	7.75
42.00	7.75



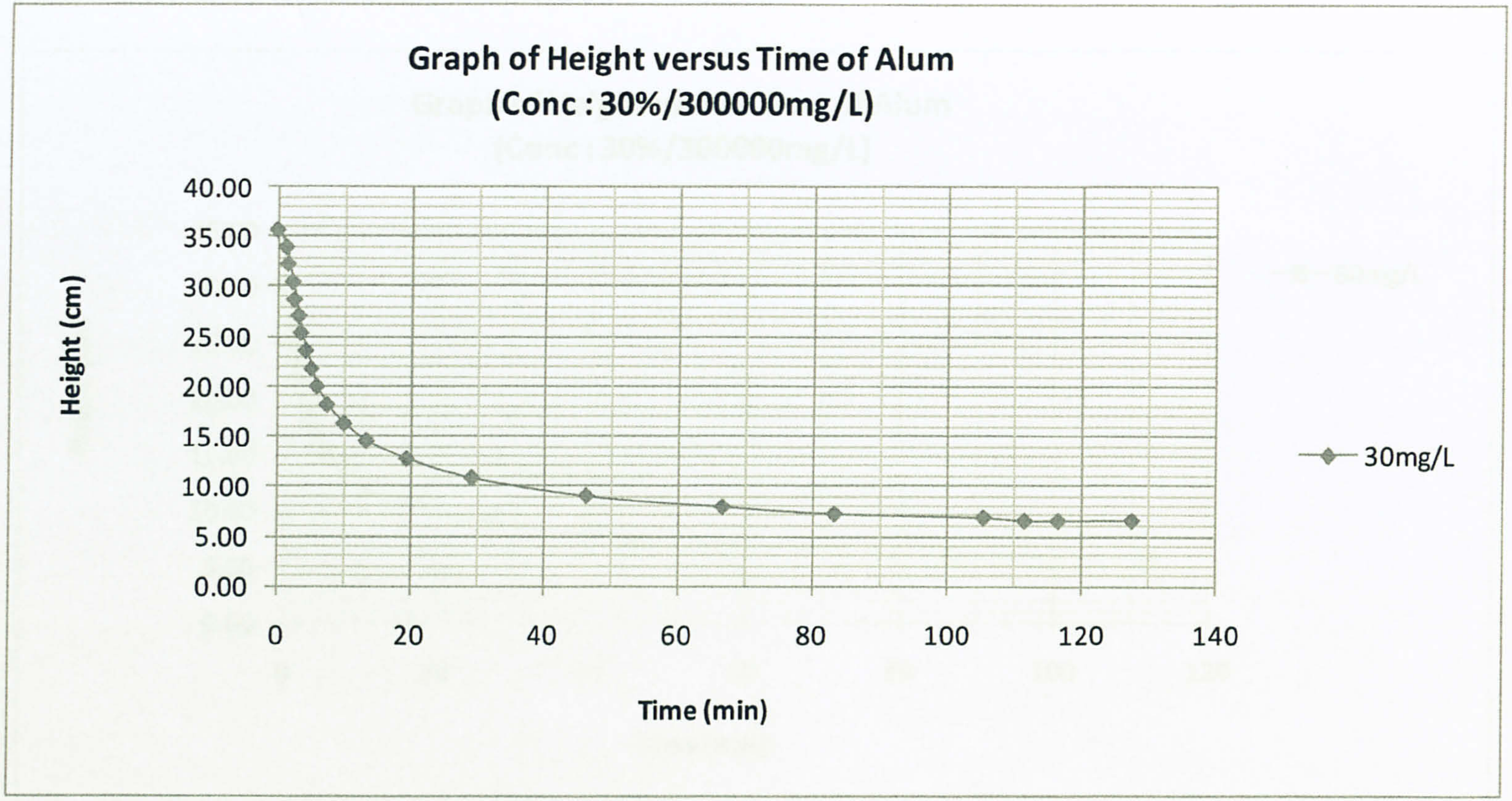
$$\frac{\Delta H}{\Delta T} = \frac{25.75 - 16.75}{5.25 - 1.5} = 2.4cm/min$$

Appendix B3: Result for Alum Settleability

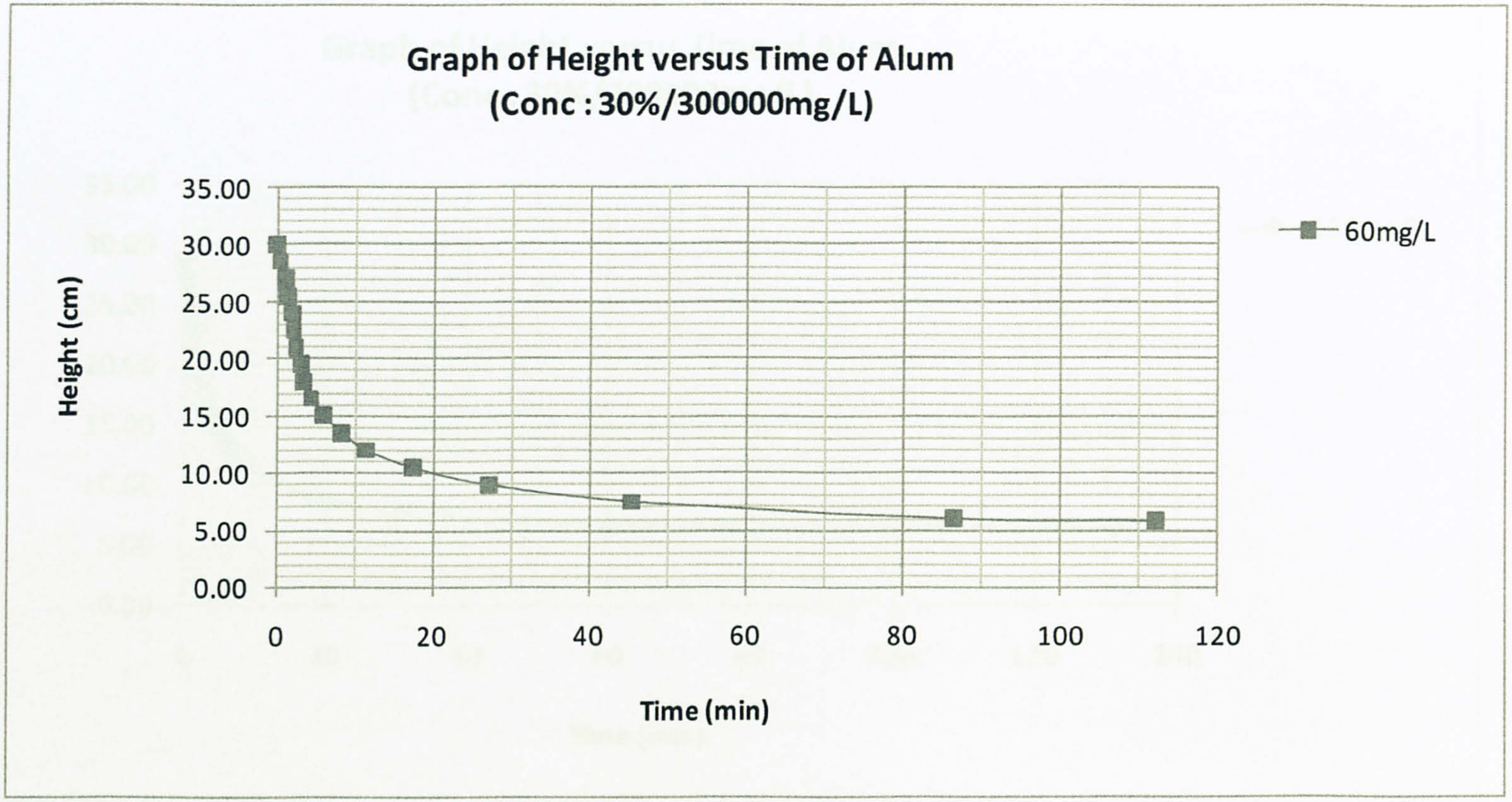
Group 1 (Alum)
Conc = 300 000mg/L =30%

JAR 1 (30mg/L)		JAR 2 (60mg/L)		JAR 3 (120mg/L)		JAR 4 (300mg/L)		JAR 5 (900mg/L)		JAR 6 (1200mg/L)	
Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)
0.00	35.70	0.00	30.00	0.00	28.70	0.00	31.50	0.00	30.25	0.00	28.50
1.32	34.00	0.52	28.50	0.31	27.30	0.11	31.20	0.37	28.85	0.36	27.10
1.59	32.30	1.19	27.00	0.54	25.90	0.43	29.80	0.53	27.45	0.56	25.70
2.27	30.50	1.40	25.50	1.12	24.50	1.04	28.40	1.06	26.05	1.13	24.30
2.53	28.70	2.01	24.00	1.30	23.10	1.28	27.00	1.19	24.65	1.26	22.90
3.20	27.10	2.20	22.50	1.43	21.70	1.48	25.60	1.31	23.25	1.41	21.50
3.50	25.40	2.43	21.00	2.04	20.30	2.19	24.20	1.48	21.85	1.58	20.10
4.27	23.60	3.10	19.50	2.31	18.90	2.48	22.80	2.06	20.45	2.16	18.70
5.15	21.80	3.51	18.00	3.00	17.50	3.22	21.40	2.33	19.05	2.42	17.30
6.00	20.00	4.48	16.50	3.48	16.10	4.06	20.00	3.04	17.65	3.18	15.90
7.54	18.20	6.09	15.00	4.44	14.70	5.10	18.60	3.51	16.25	4.09	14.50
10.02	16.30	8.28	13.50	6.18	13.30	6.27	17.20	5.18	14.80	5.28	13.10
13.43	14.60	11.49	12.00	8.36	11.90	8.24	15.80	7.00	13.35	7.30	11.70
19.45	12.80	17.47	10.50	12.06	10.50	11.09	14.40	9.58	11.90	10.23	10.30
29.20	10.90	27.20	9.00	17.58	9.10	15.06	13.00	15.58	10.45	15.53	8.90
46.30	9.10	45.45	7.50	30.32	7.70	21.50	11.60	24.14	9.00	26.19	7.50
66.55	8.00	86.39	6.00	59.55	6.80	36.26	10.20	62.18	7.55	63.36	6.10
83.13	7.30	112.14	5.80	131.20	6.30	80.11	6.80	73.20	5.80	90.00	5.80
105.30	6.90					85.26	6.80			95.00	5.80
111.41	6.60					90.02	6.80			100.00	5.80
116.41	6.60					95.10	6.80				
127.41	6.60										

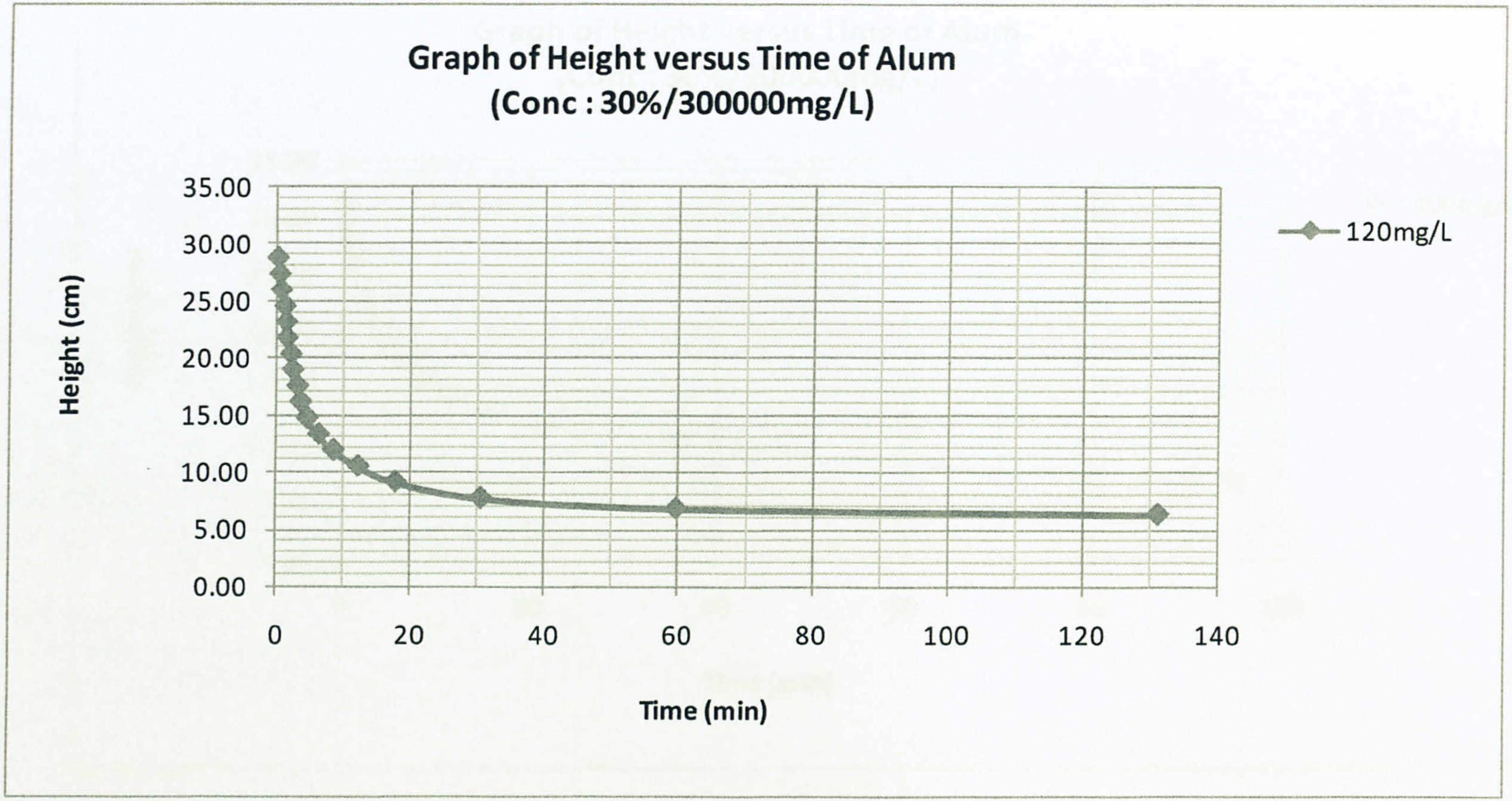
Appendix B3-1



$$\frac{\Delta H}{\Delta T} = \frac{36-0}{13} = 2.769cm/min$$

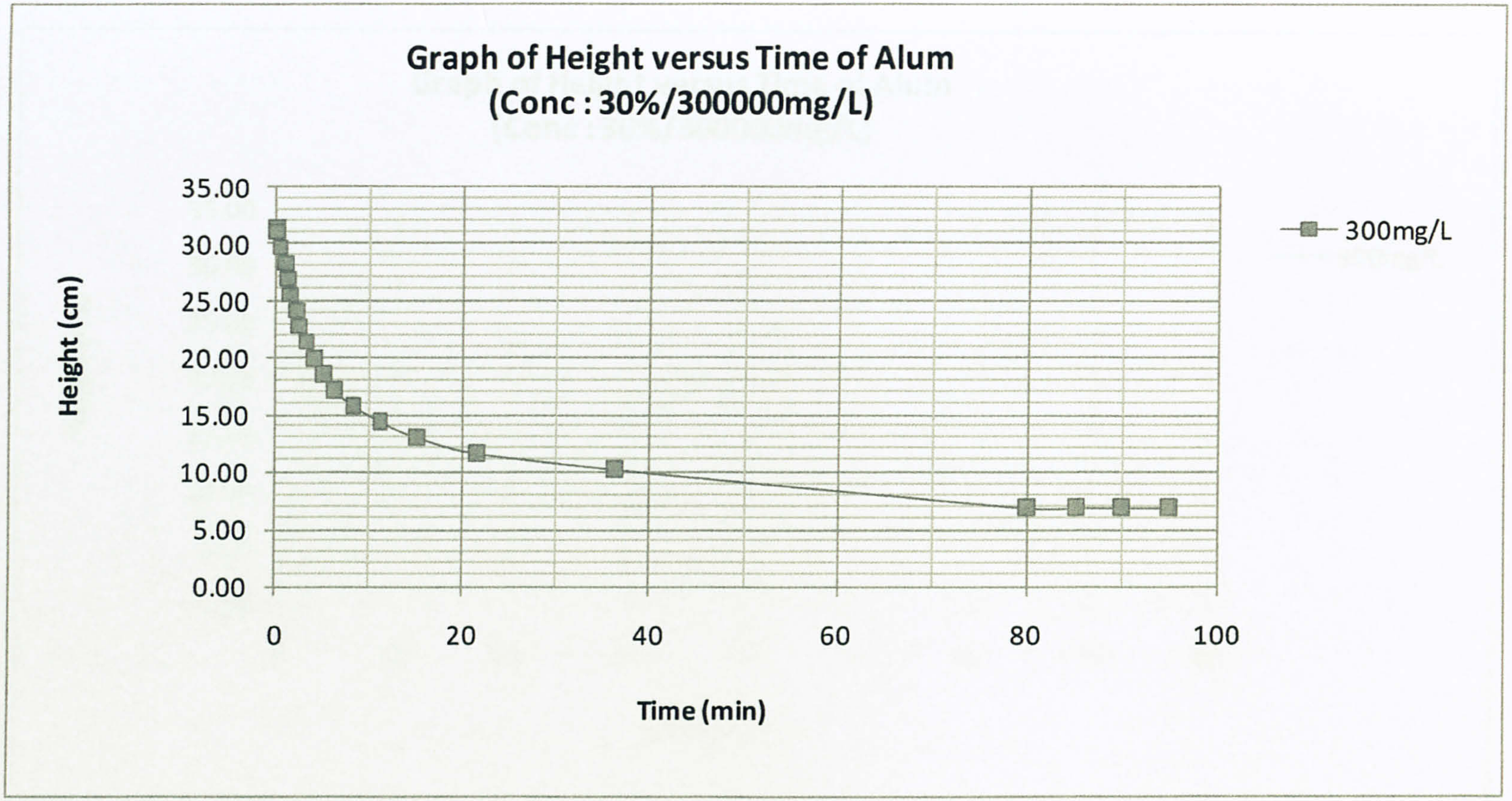


$$\frac{\Delta H}{\Delta T} = \frac{30 - 0}{9} = 3.33cm/min$$

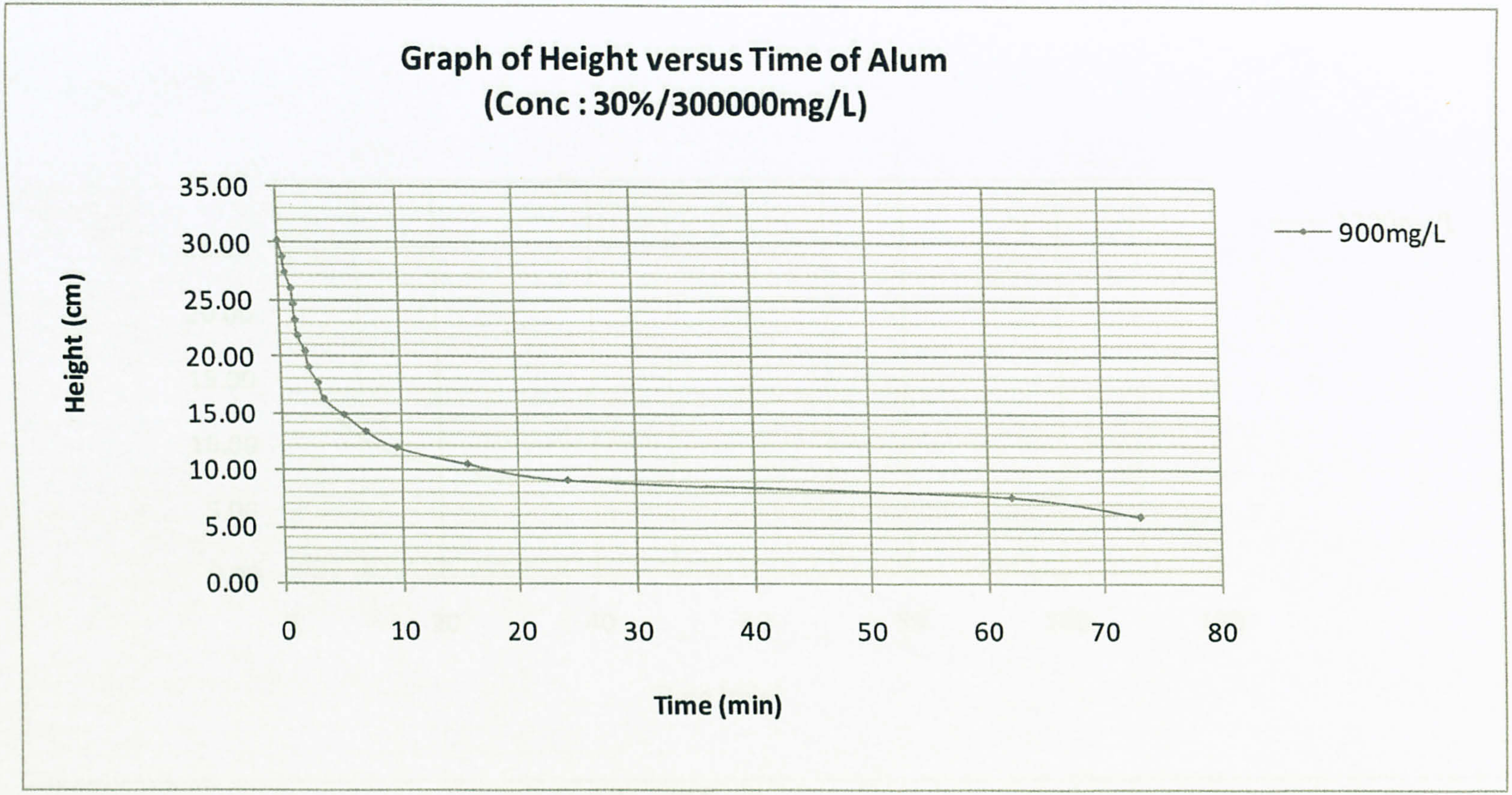


$$\frac{\Delta H}{\Delta T} = \frac{29 - 0}{8} = 3.625cm/min$$

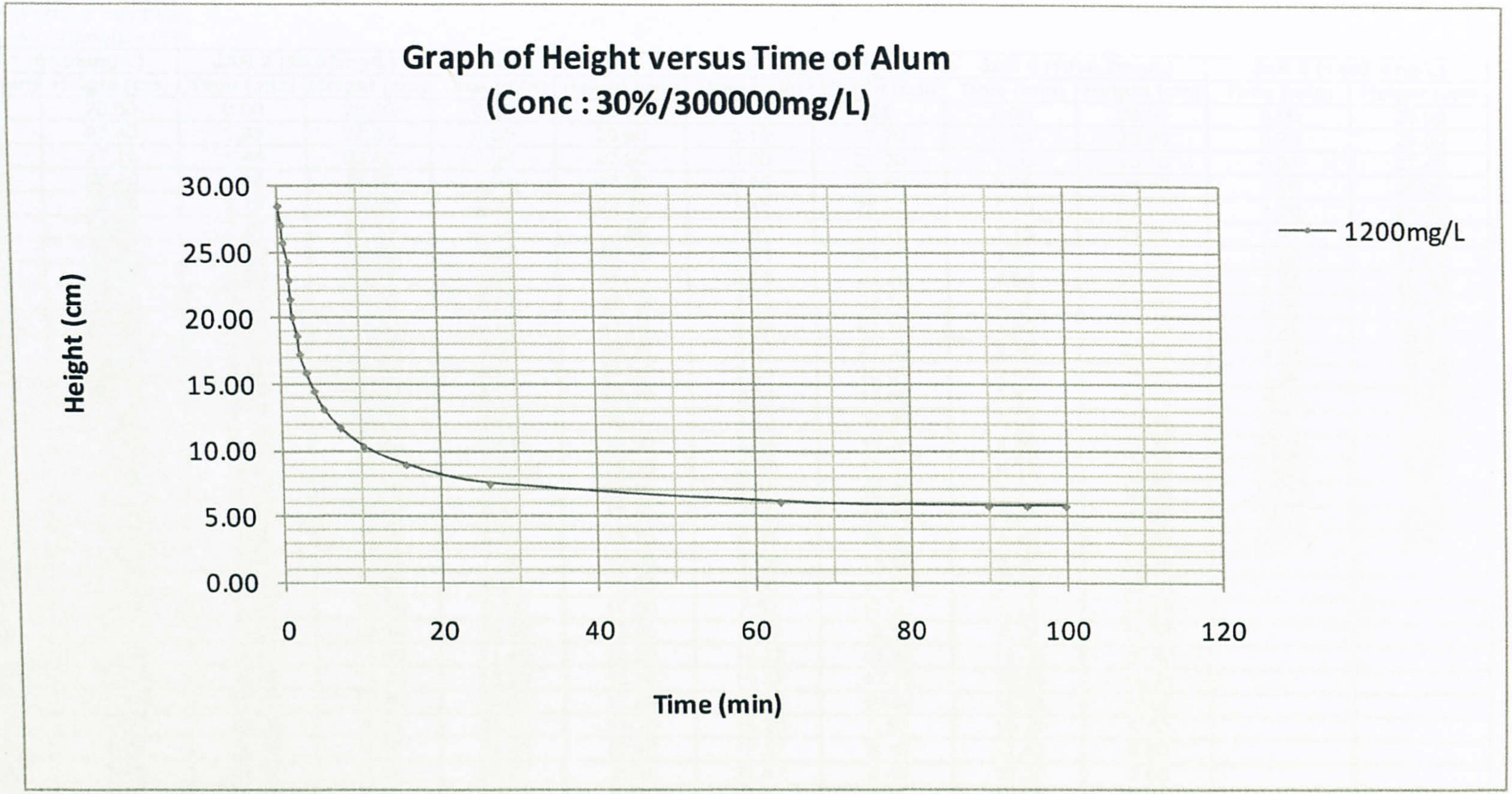
Appendix B3-4



$$\frac{\Delta H}{\Delta T} = \frac{31.5 - 0}{10} = 3.15 cm/min$$



$$\frac{\Delta H}{\Delta T} = \frac{30 - 0}{6.25} = 4.8cm/min$$

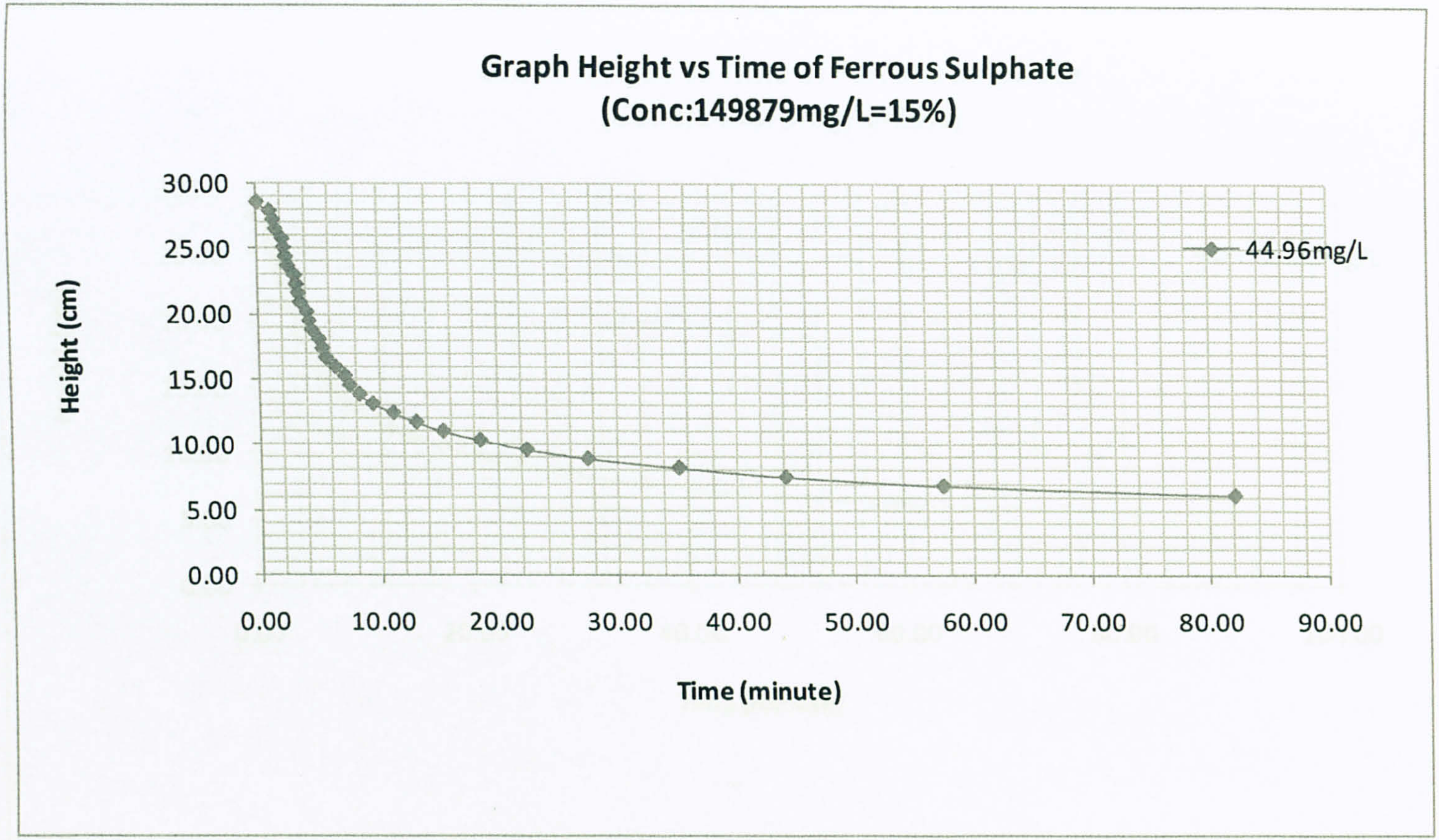


$$\frac{\Delta H}{\Delta T} = \frac{28.5 - 0}{6} = 4.75cm/min$$

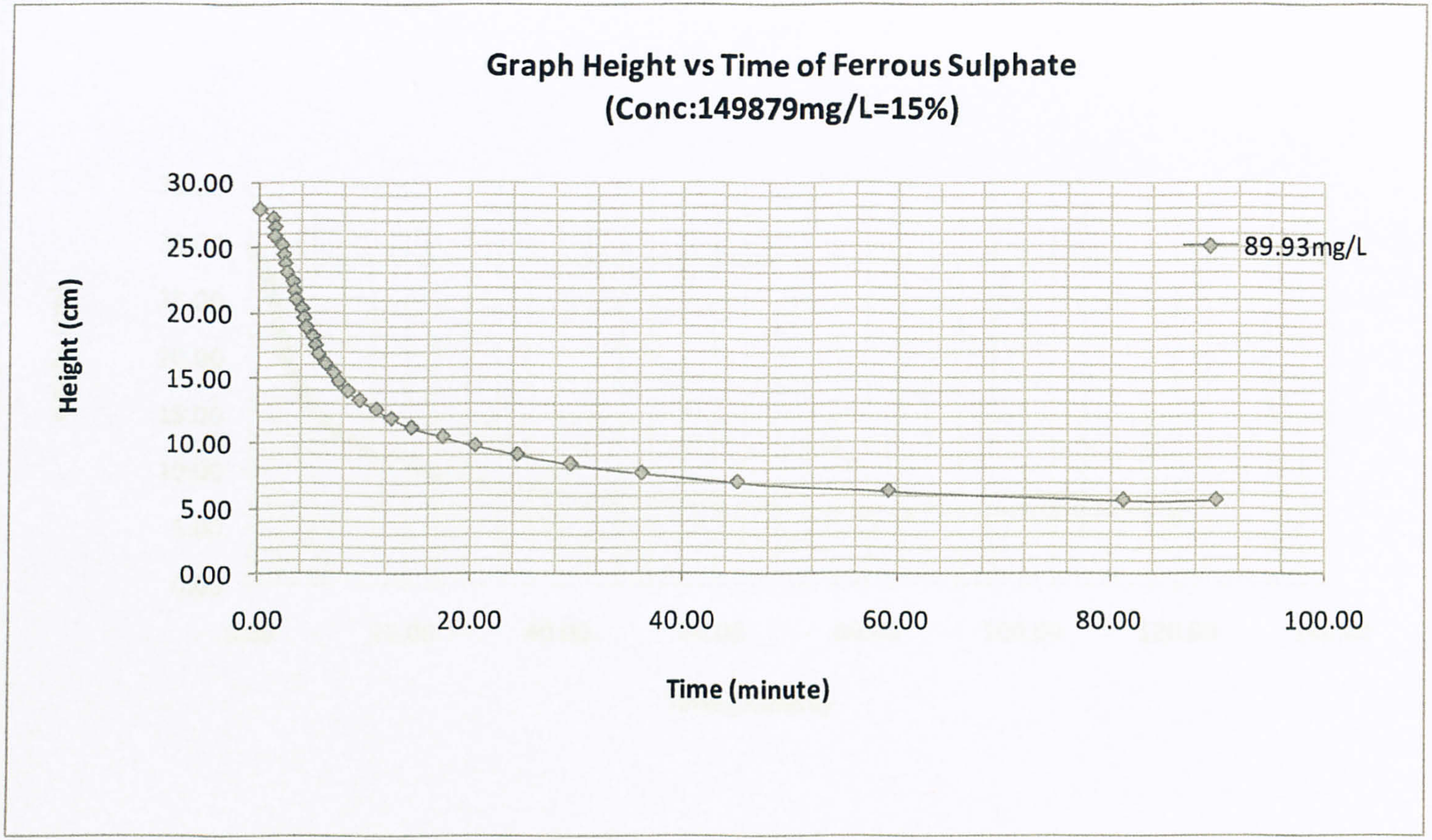
Appendix B4: Result for Ferrous Sulphate Settleability

Group 2 (Ferrous Sulphate)
Conc = 149 879mg/L =15%

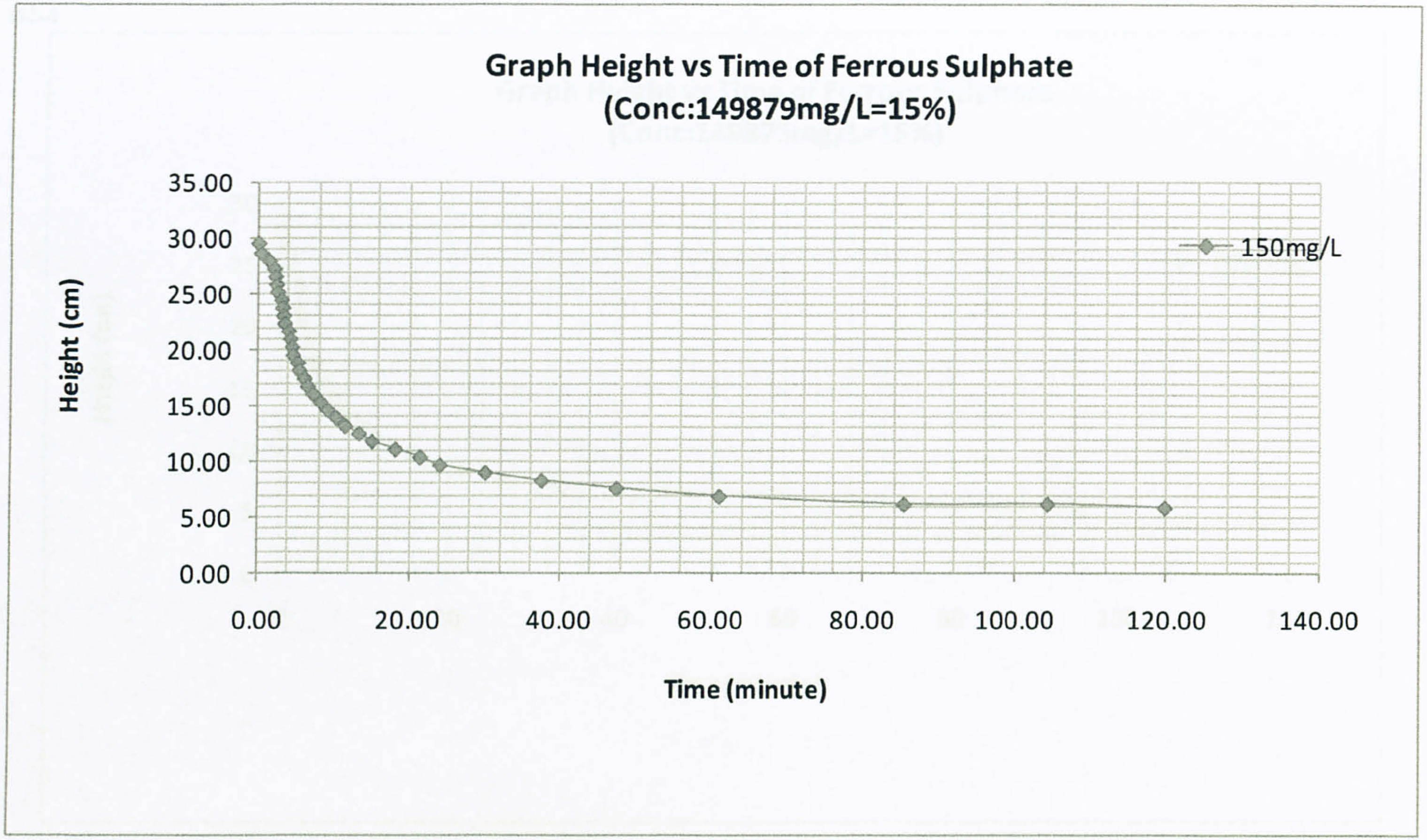
JAR 1 (44.96mg/L)		JAR 2 (89.93mg/L)		JAR 3 (150mg/L)		JAR 4 (299.7mg/L)		JAR 5 (1049.2mg/L)		JAR 6 (1498.8mg/L)	
Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)
0.00	28.50	0.00	28.00	0.00	29.50	0	28	0.00	28.50	0.00	29.90
1.06	27.80	1.25	27.30	0.35	28.60	0.19	27.70	0.36	26.80	0.20	29.60
1.33	27.10	1.44	26.60	1.39	27.90	0.30	27.30	1.00	26.10	0.31	27.40
1.52	26.40	1.38	25.90	2.04	27.20	0.55	26.60	1.08	25.40	1.00	26.00
2.08	25.70	2.12	25.20	2.22	26.50	1.15	25.90	1.19	24.70	1.20	24.60
2.17	25.00	2.29	24.50	2.35	25.80	1.40	25.20	1.45	24.00	1.41	23.20
2.34	24.30	2.43	23.80	2.46	25.10	1.51	24.50	1.51	23.30	2.03	21.80
2.48	23.60	2.59	23.10	3.01	24.40	2.03	23.80	2.04	22.60	2.28	20.40
3.03	22.90	3.14	22.40	3.16	23.70	2.12	23.10	2.16	21.90	2.54	19.00
3.16	22.20	3.30	21.70	3.28	23.00	2.26	21.70	2.30	21.20	3.26	18.00
3.32	21.50	3.45	21.00	3.43	22.30	2.37	21.00	2.40	20.50	4.04	16.00
3.47	20.80	4.02	20.30	4.00	21.60	2.51	20.30	2.58	19.80	5.02	14.60
4.04	20.10	4.18	19.60	4.21	20.90	3.01	19.60	3.13	19.10	6.20	13.10
4.20	19.40	4.37	18.90	4.46	20.20	3.13	18.90	3.31	18.40	8.13	11.80
4.41	18.70	5.02	18.20	4.58	19.50	3.34	18.20	3.48	17.70	11.20	10.30
5.01	18.00	5.27	17.50	5.21	18.80	3.56	17.50	4.12	17.00	16.29	8.90
5.29	17.30	5.53	16.80	5.45	18.10	4.16	16.80	4.37	16.30	29.37	7.50
5.57	16.60	6.22	16.10	6.11	17.40	4.42	16.10	5.07	15.60	54.22	6.80
6.32	15.90	7.00	15.40	6.53	16.70	5.23	15.40	5.42	14.90	109.22	6.30
7.09	15.20	7.48	14.70	7.28	16.00	6.09	14.70	6.30	14.20		
7.49	14.50	8.34	14.00	8.20	15.30	6.56	14.00	7.16	13.50		
8.31	13.80	9.44	13.30	9.16	14.60	7.52	13.30	8.22	12.80		
9.40	13.10	11.06	12.60	10.32	13.90	8.53	12.60	9.37	12.10		
11.12	12.40	12.46	11.90	11.48	13.20	10.22	11.90	11.04	11.40		
13.05	11.70	14.40	11.20	13.28	12.50	11.37	11.20	12.53	10.70		
15.30	11.00	17.33	10.50	15.05	11.80	13.10	10.50	15.54	10.00		
18.45	10.30	20.35	9.80	18.12	11.10	15.20	9.80	18.22	9.30		
22.34	9.60	24.36	9.10	21.42	10.40	17.37	9.10	22.40	8.60		
27.52	8.90	29.37	8.40	24.07	9.70	21.47	8.40	30.30	7.90		
35.21	8.20	36.10	7.70	30.05	9.00	26.14	7.70	49.26	7.10		
44.19	7.50	45.01	7.00	37.49	8.30	33.59	7.00	97.10	6.40		
57.49	6.80	59.20	6.30	47.46	7.60	59.38	6.30				
82.10	6.10	81.20	5.60	61.01	6.90	69.11	5.60				
		90.00	5.60	85.45	6.20	95.59	4.90				
				104.48	6.20						
				120.00	5.90						



$$\frac{\Delta H}{\Delta T} = \frac{30-0}{11} = 2.72cm/min$$

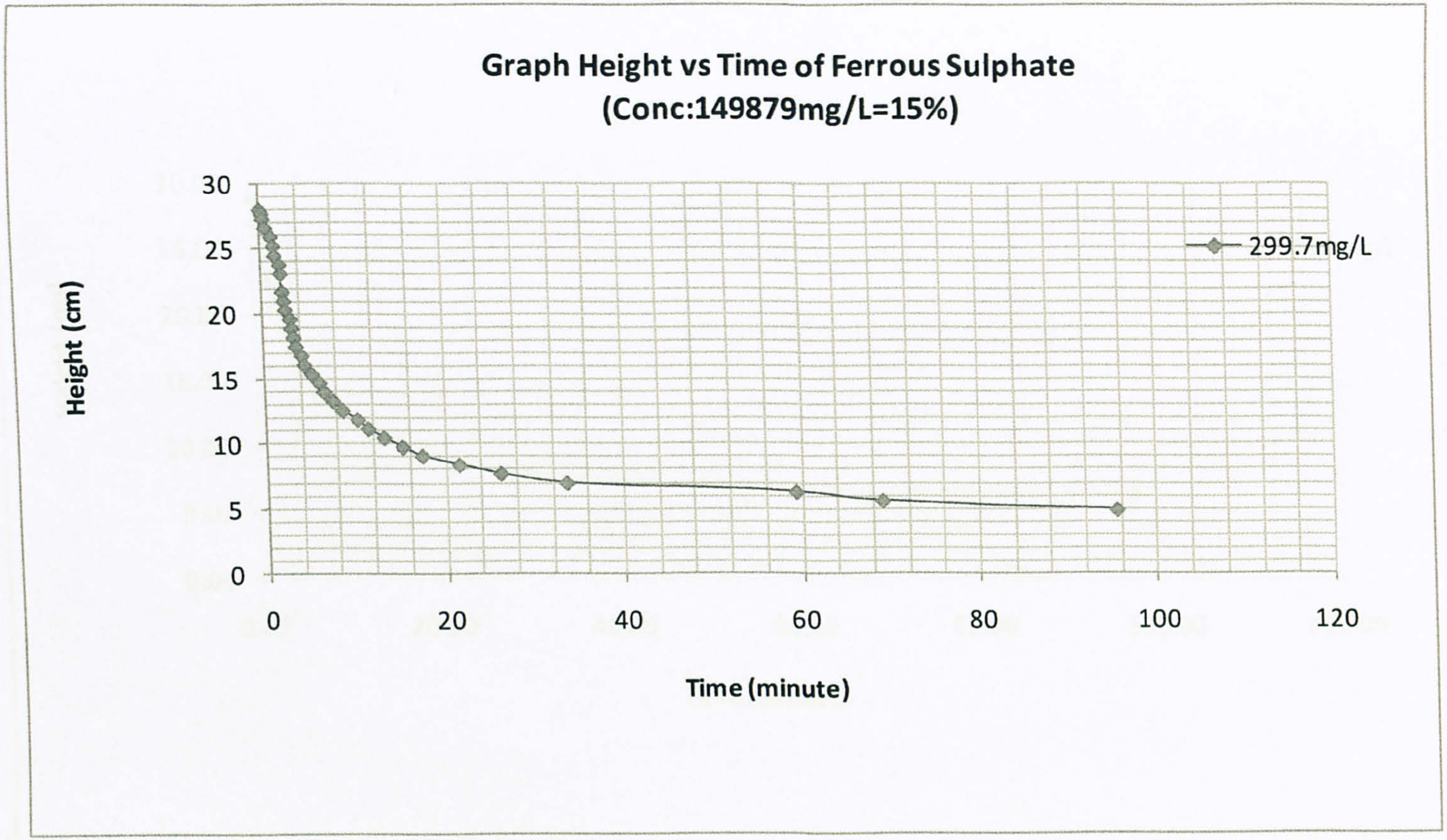


$$\frac{\Delta H}{\Delta T} = \frac{28 - 0}{13} = 2.15cm/min$$



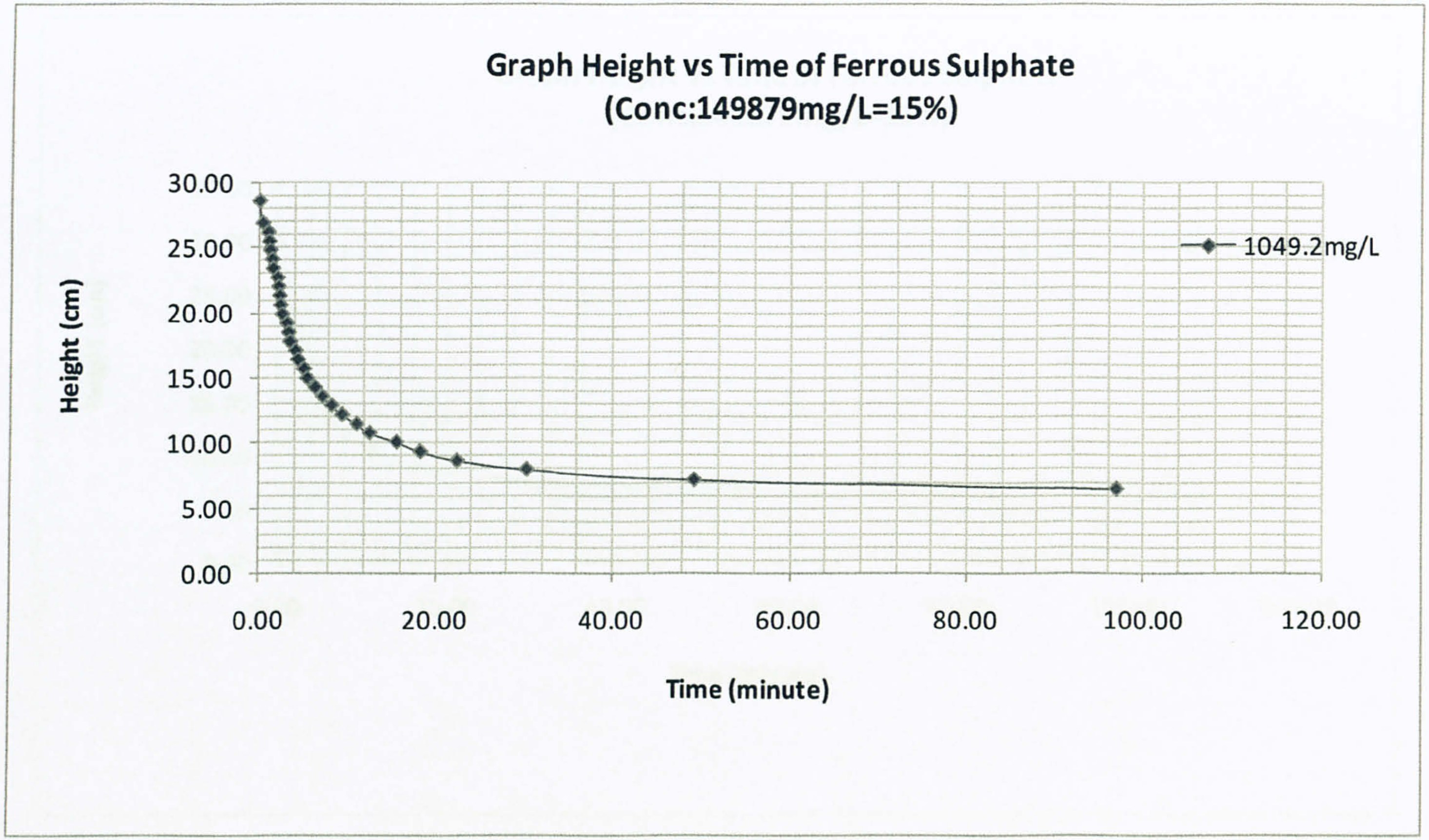
$$\frac{\Delta H}{\Delta T} = \frac{29 - 0}{13} = 2.23 cm/min$$

Appendix B4-4

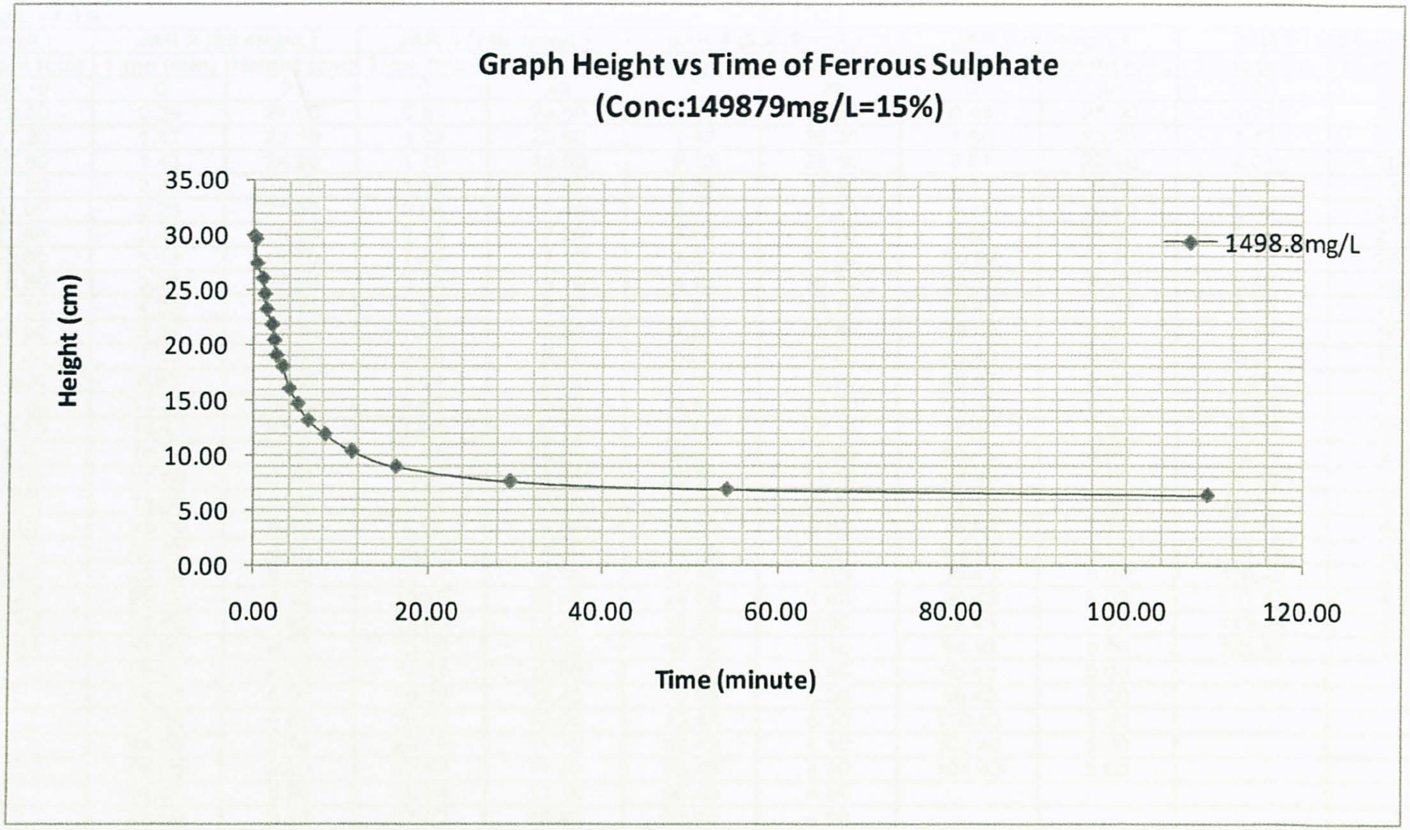


$$\frac{\Delta H}{\Delta T} = \frac{28 - 0}{9} = 3.11 cm/min$$

Appendix B4-5



$$\frac{\Delta H}{\Delta T} = \frac{28.5 - 0}{9} = 3.17 cm/min$$

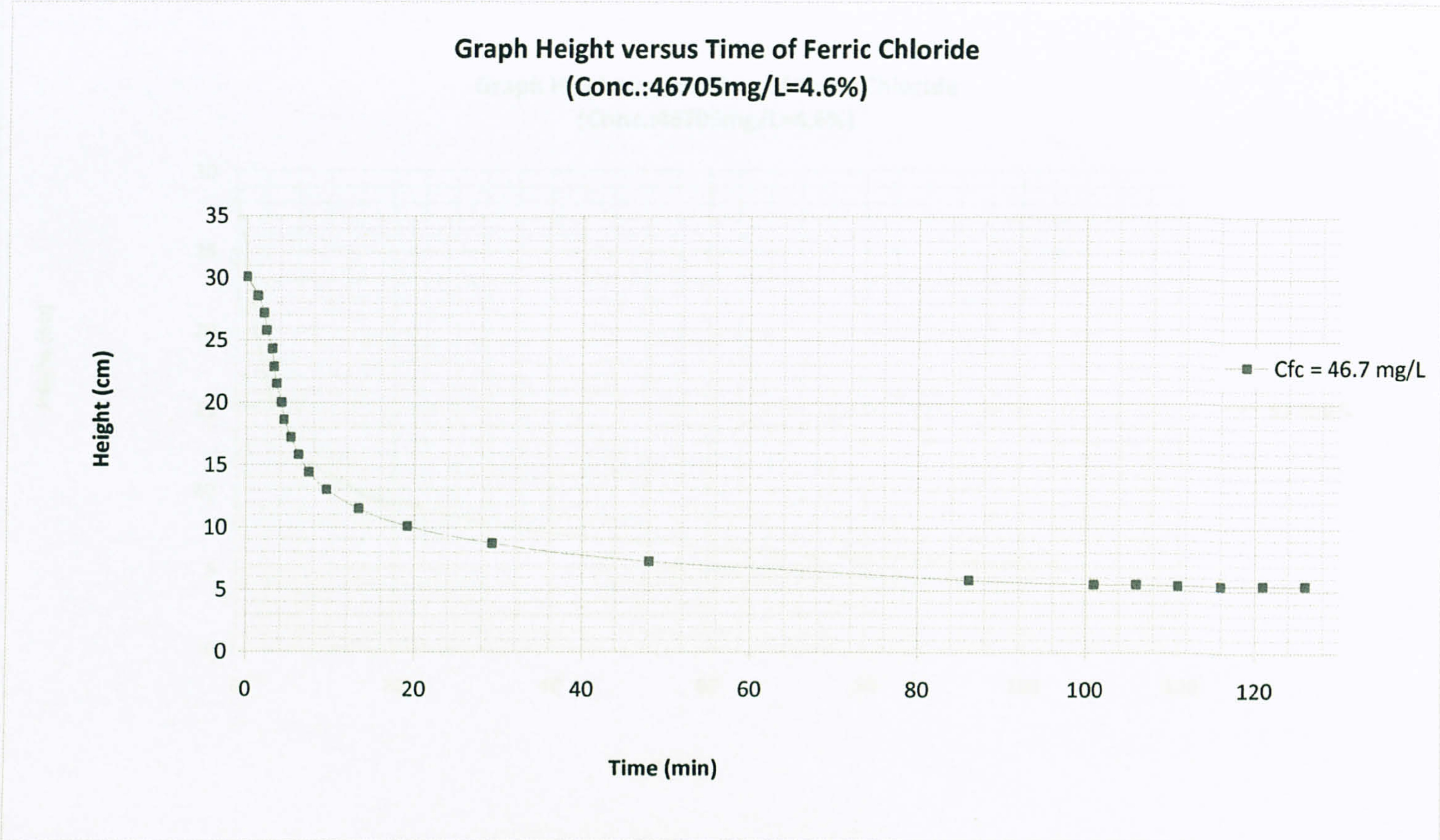


$$\frac{\Delta H}{\Delta T} = \frac{30 - 0}{8} = 3.75 cm/min$$

Appendix B5: Result for Ferric Chloride Settleability

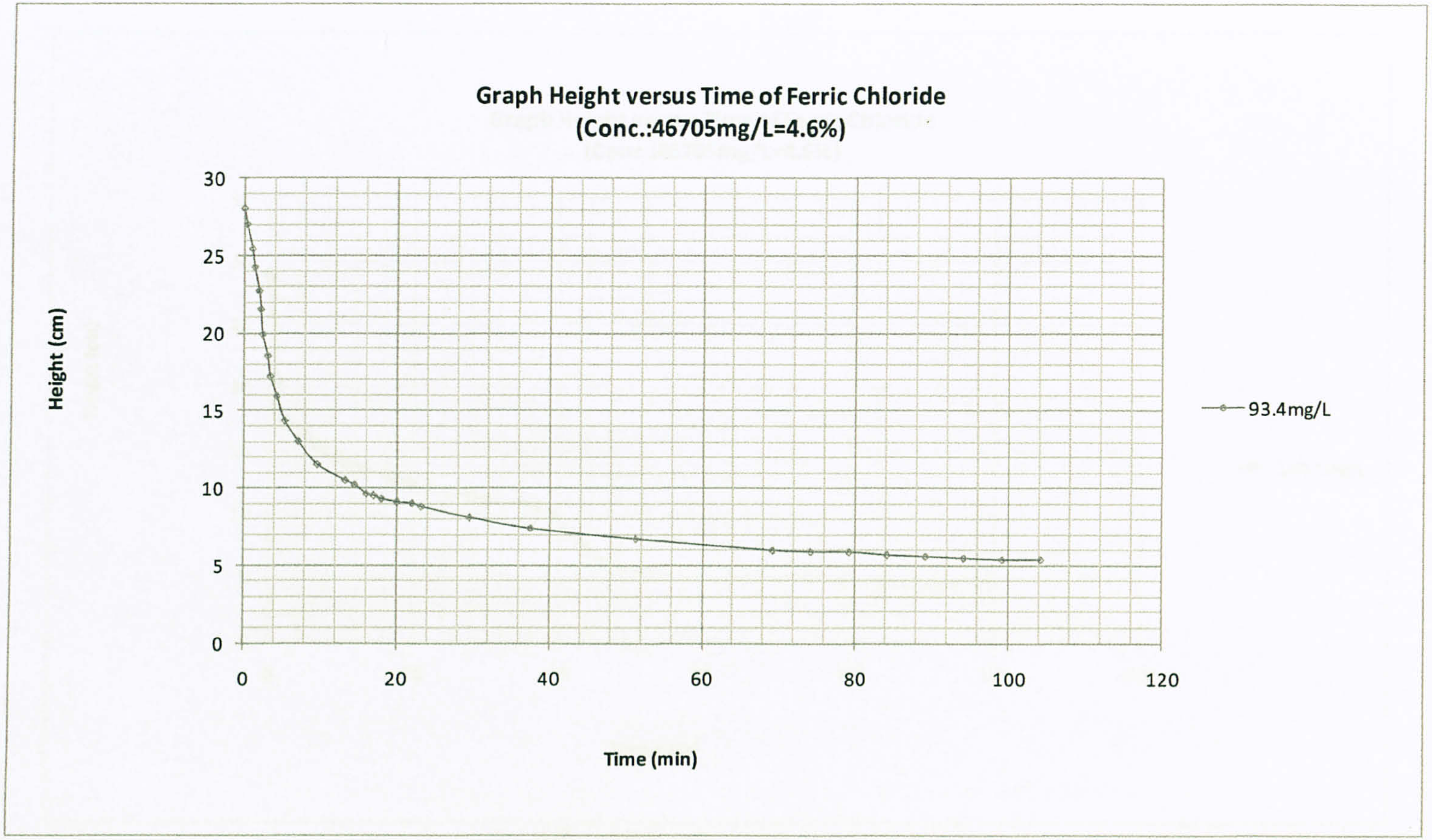
Group 3 (Ferri Chlorate)
Conc = 46 705mg/L =4.6%

JAR 1 (46.7mg/L)		JAR 2 (93.4mg/L)		JAR 3 (140.1mg/L)		JAR 4 (233.5mg/L)		JAR 5 (934mg/L)		JAR 6 (1401mg/L)	
Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)
0.00	30.10	0	28	0	29	0	28	0	28	0.00	31.00
1.30	28.60	0.39	27.00	0.51	28.50	0.46	27.80	0.45	28.00	1.21	29.00
2.05	27.20	1.12	25.40	1.03	20.50	1.47	26.30	1.50	25.20	1.42	27.60
2.36	25.80	1.43	24.20	1.19	18.50	2.13	23.80	2.31	22.40	2.01	26.00
3.03	24.30	2.00	22.70	1.36	17.90	2.26	22.50	3.11	19.60	2.20	24.60
3.25	22.90	2.23	21.50	2.04	17.40	3.03	21.20	4.11	16.80	2.36	23.20
3.54	21.50	2.46	19.90	2.18	17.20	3.24	19.00	5.56	14.00	2.54	21.80
4.14	20.00	3.13	18.50	2.49	17.10	3.37	18.30	10.29	11.20	3.15	20.40
4.46	18.60	3.47	17.20	3.22	16.70	4.10	16.80	22.13	8.40	3.40	19.00
5.29	17.20	4.33	15.90	4.10	16.50	4.32	16.10	33.43	7.00	4.10	17.50
6.22	15.80	5.34	14.30	4.18	16.30	4.52	15.40	38.43	6.60	4.59	16.10
7.41	14.40	7.15	13.00	4.40	16.20	5.22	14.60	43.43	6.30	6.11	14.60
9.53	13.00	9.58	11.50	5.59	15.90	5.56	13.90	48.43	6.30	8.09	13.20
13.34	11.50	13.25	10.50	6.49	15.60	6.42	13.20	53.43	6.10	11.02	11.80
19.17	10.10	14.47	10.20	7.32	15.30	7.40	12.50	58.43	5.80	15.36	10.30
29.30	8.70	16.00	9.60	7.52	15.20	8.52	11.80	63.43	5.60	23.20	8.40
48.00	7.30	17.00	9.50	8.35	14.90	10.31	11.10	68.43	5.30	36.16	7.40
86.14	5.80	18.00	9.30	9.03	14.70	12.30	10.30	73.43	5.30	66.47	6.00
101.00	5.50	20.00	9.10	9.16	14.40	15.03	9.60	78.43	5.20	71.47	6.00
106.00	5.50	22.00	9.00	10.00	14.20	18.30	8.90	83.43	5.10	101.47	5.30
111.00	5.40	23.18	8.80	11.11	13.90	22.45	8.30	88.43	5.00	106.47	5.30
116.00	5.40	29.52	8.10	12.15	13.60	28.59	7.40	90.43	5.00	111.47	5.30
121.00	5.40	37.50	7.40	13.05	13.40	36.22	6.80	92.43	5.00	116.47	5.30
126.00	5.40	51.24	6.70	16.20	13.20	48.10	6.10	94.43	5.00	121.47	5.30
		69.01	6.00	17.11	12.80	64.43	5.40	96.43	5.00		
		74.00	5.90	19.32	12.40	70.43	5.30	98.43	5.00		
		79.00	5.89	22.23	12.00	75.43	5.10	100.43	5.00		
		84.00	5.70	25.15	11.70	80.43	5.10	102.43	5.00		
		89.00	5.60	27.47	11.40	85.43	4.80	104.43	5.00		
		94.00	5.50	30.04	11.10	90.43	4.80				
		99.00	5.40	37.02	10.60	95.43	4.80				
		104.00	5.40	39.43	9.70	100.43	4.70				
				43.11	7.50	105.43	4.60				
				51.51	5.30	115.43	4.60				
				74.50	5.00	120.43	4.60				
				79.50	4.70	125.43	4.60				
				84.50	4.50						
				89.50	4.40						
				94.50	4.40						
				99.50	4.40						



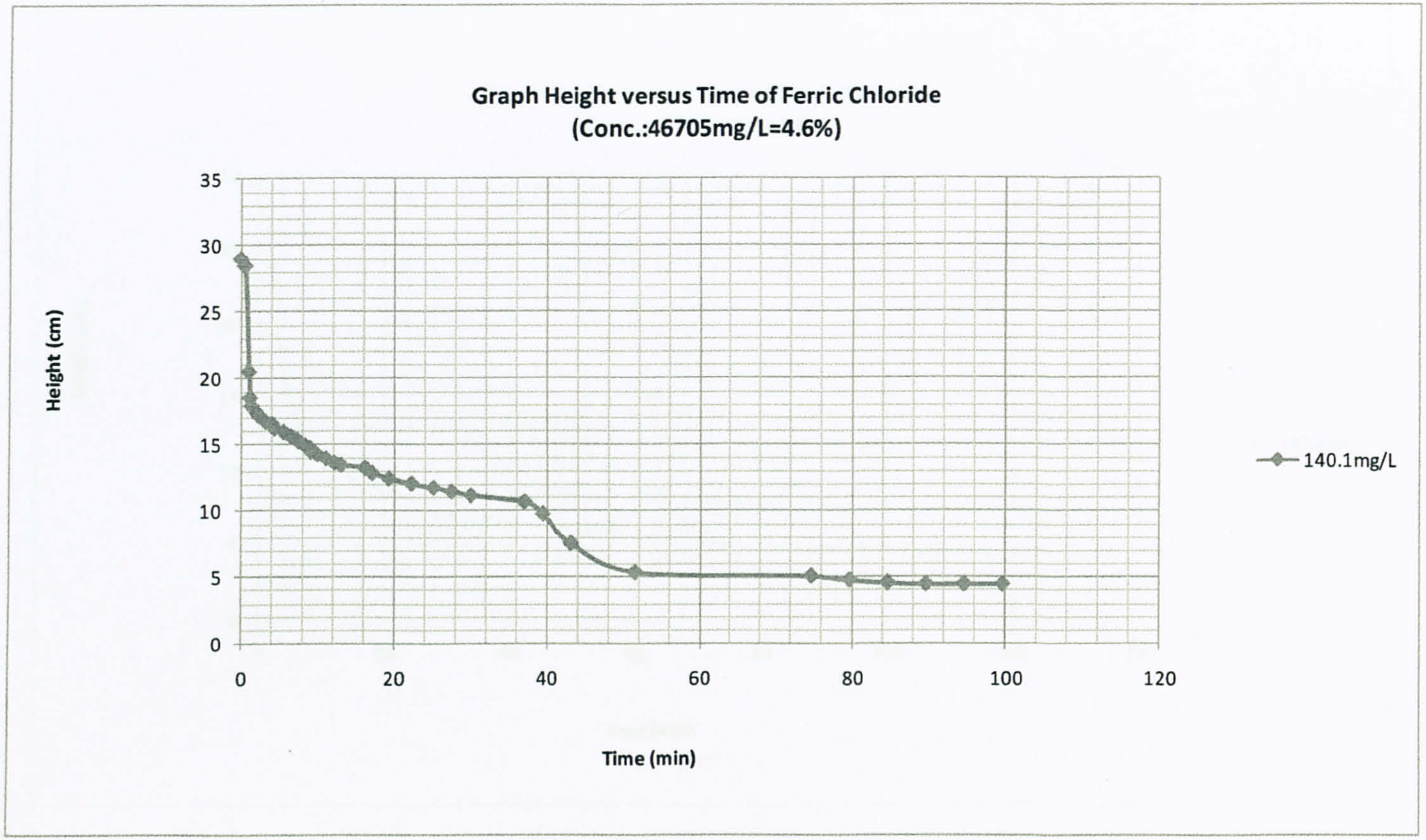
$$\frac{\Delta H}{\Delta T} = \frac{30}{12} = 2.5cm/\min$$

Appendix B5-2



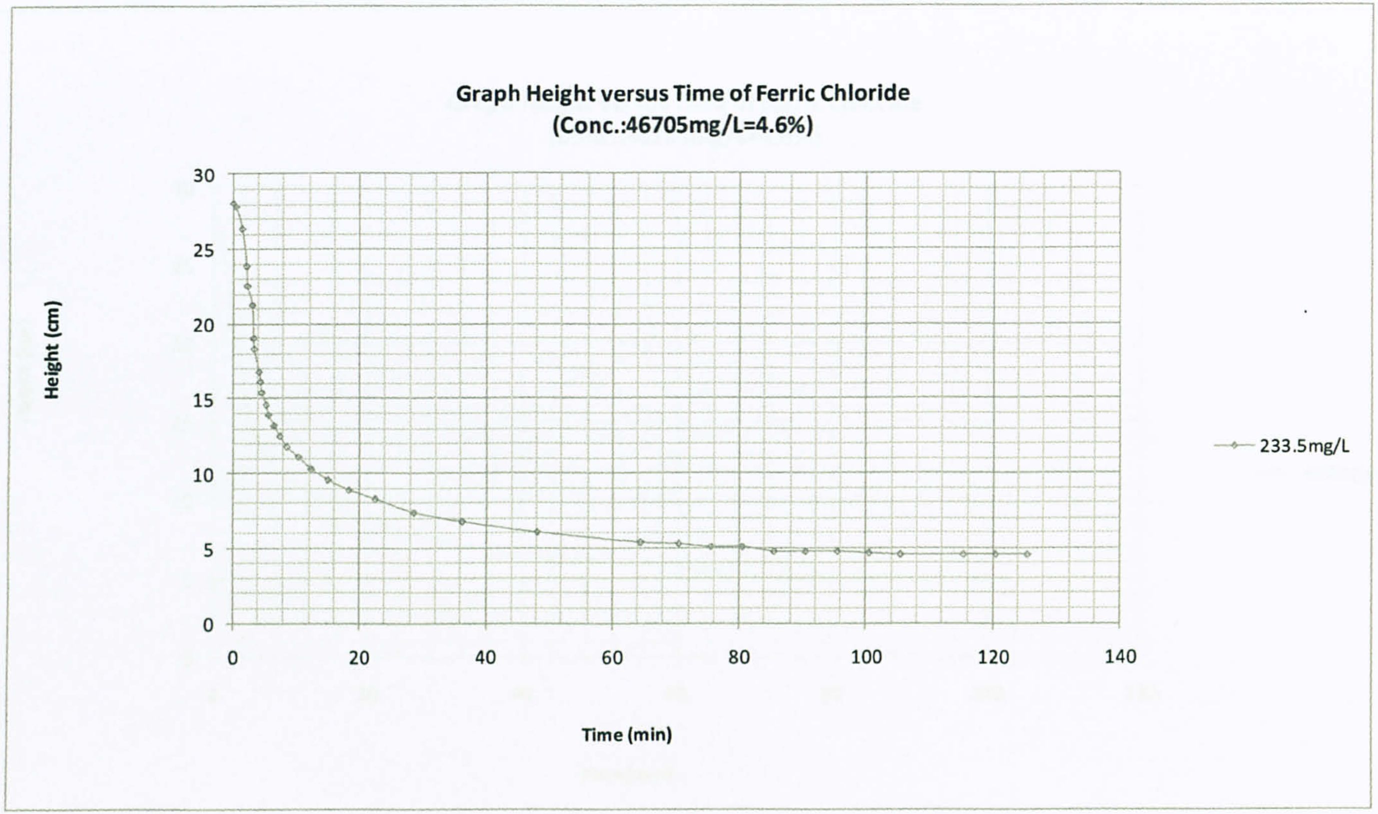
$$\frac{\Delta H}{\Delta T} = \frac{28-0}{9} = 3.11 cm/min$$

Appendix B5-3

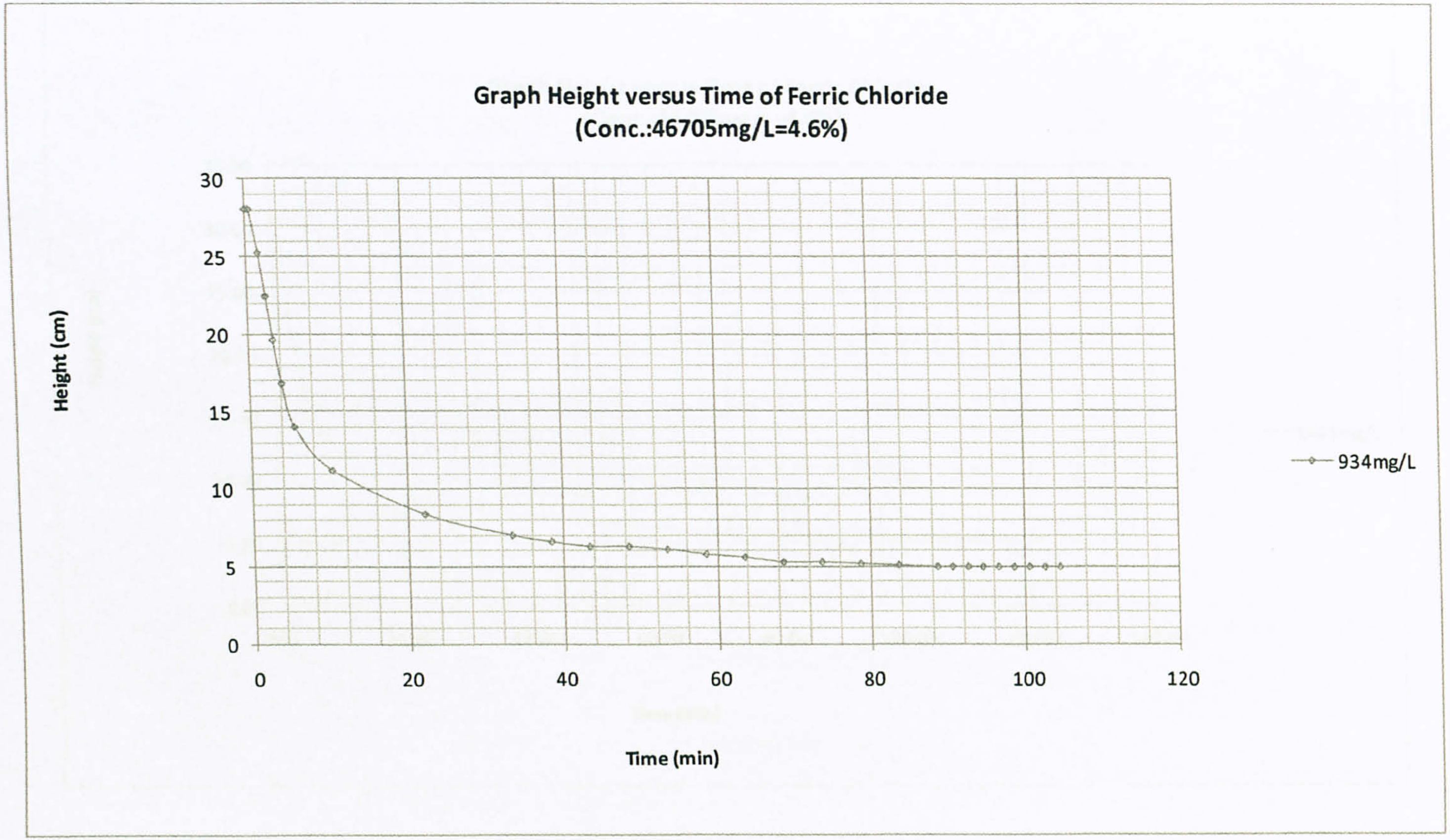


$$\frac{\Delta H}{\Delta T} = \frac{18.5 - 0}{41} = 0.45cm/min$$

Appendix B5-4

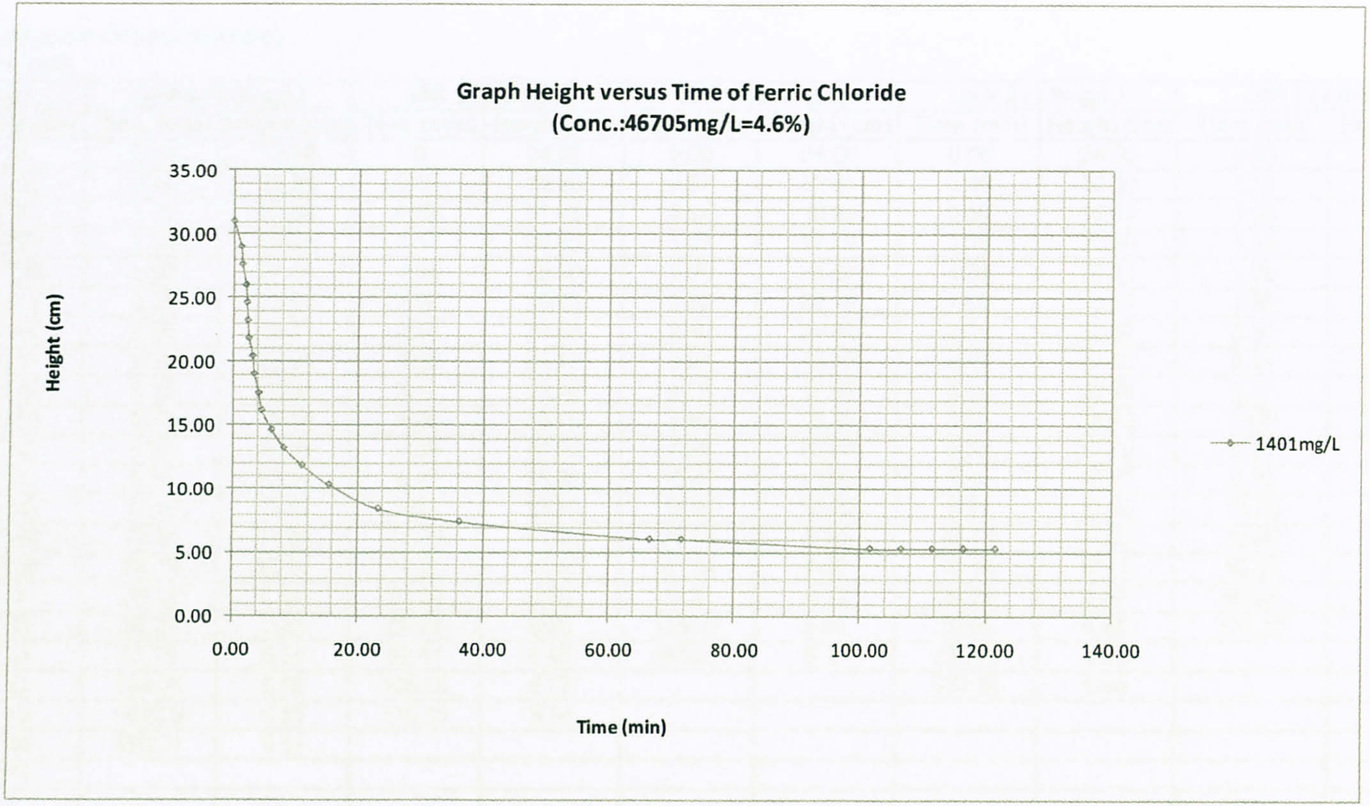


$$\frac{\Delta H}{\Delta T} = \frac{28 - 0}{9} = 3.11 cm/min$$



$$\frac{\Delta H}{\Delta T} = \frac{29 - 0}{10} = 2.9cm/min$$

Appendix B5-6

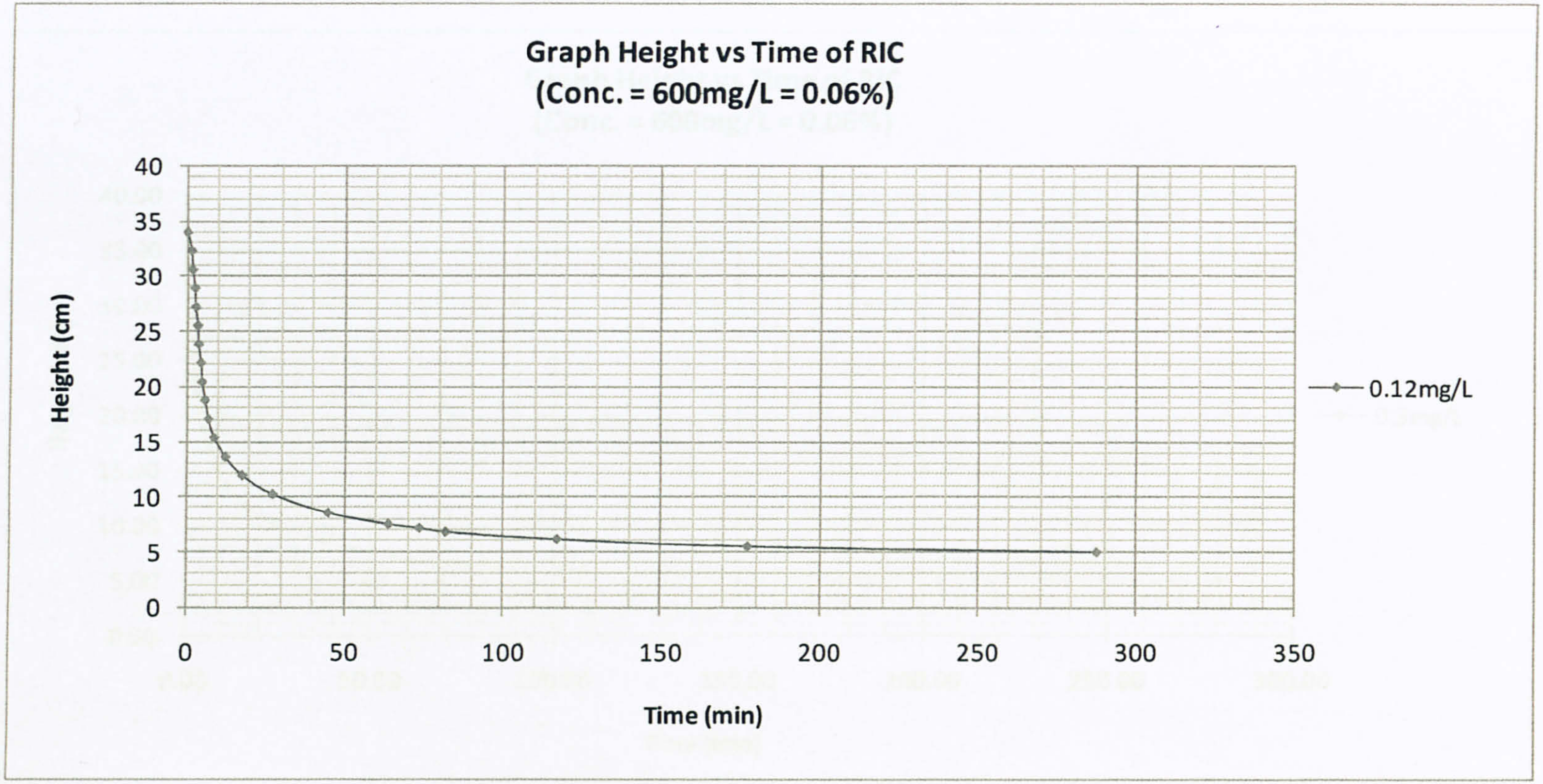


$$\frac{\Delta H}{\Delta T} = \frac{31 - 0}{8} = 3.875cm/min$$

Appendix B6: Result for Ferric Chloride Settleability

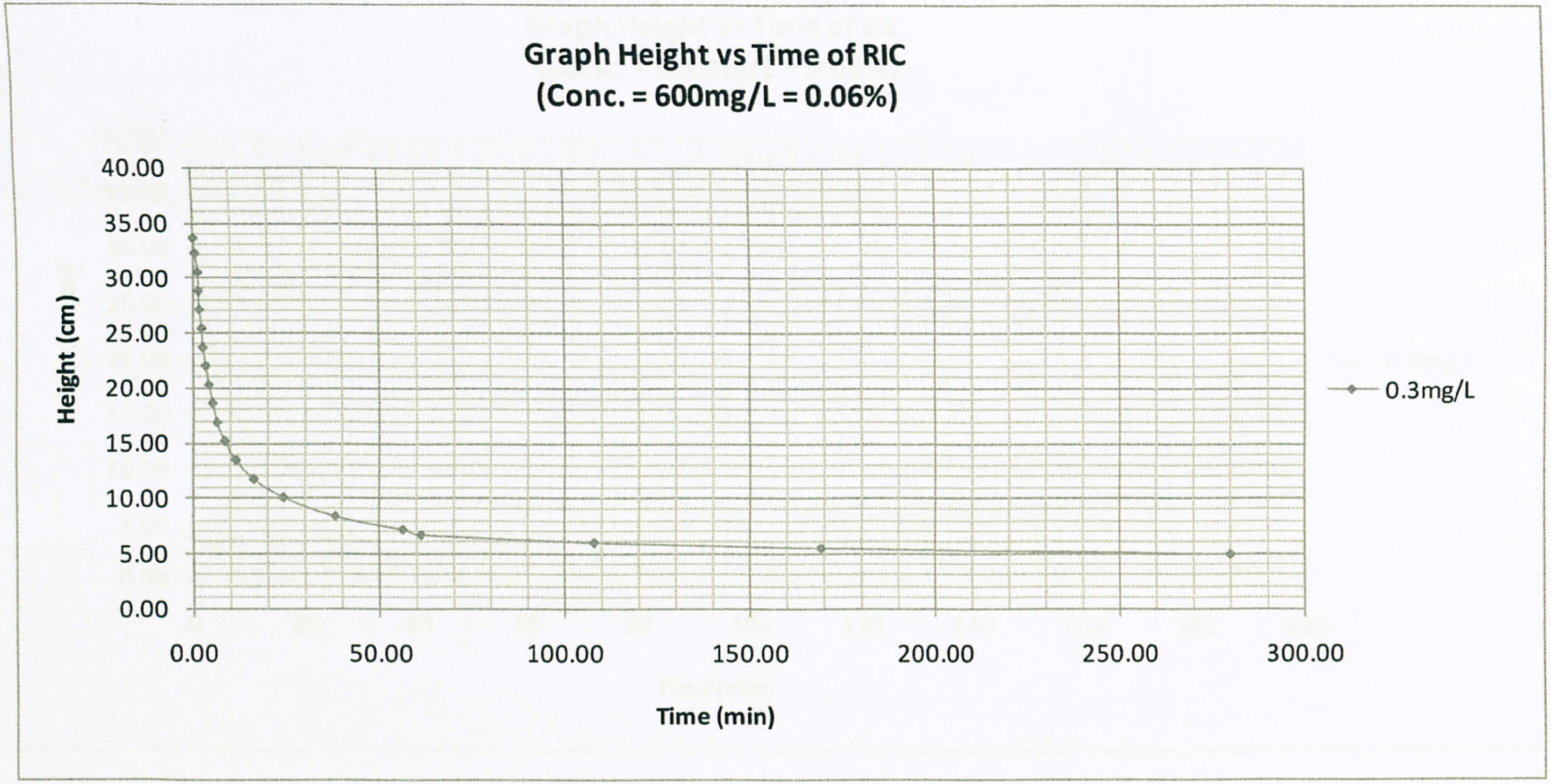
Mat's (Recycled Coagulant-Ferrous Sulphate)
Conc = 600mg/L =0,06%

JAR 1 (0.12mg/L)		JAR 2 (0.3mg/L)		JAR 3 (0.9mg/L)		JAR 4 (2.4mg/L)		JAR 5 (3.6mg/L)		JAR 6 (4.8mg/L)	
Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)	Time (min)	Height (cm)
0	34	0.00	33.60	0	34.00	0.00	34.00	0.00	34.00	0.00	34.00
1.26	32.30	0.44	32.24	0.37	32.30	0.37	32.30	0.36	32.30	0.38	32.30
1.58	30.60	1.12	30.54	0.59	31.45	0.54	30.60	0.56	30.60	1.00	30.60
2.24	28.90	1.35	28.84	1.17	30.60	1.27	27.20	1.18	28.90	1.19	28.90
2.50	27.20	1.59	27.14	1.38	28.90	2.00	23.80	1.36	27.20	1.36	27.20
3.21	25.50	2.25	25.44	2.00	25.50	2.22	22.10	1.56	25.50	1.56	25.50
3.48	23.80	2.55	23.74	2.22	23.80	2.40	20.40	2.16	23.80	2.14	23.80
4.21	22.10	3.30	22.04	2.50	22.10	3.24	18.70	2.39	22.10	2.24	22.10
4.58	20.40	4.12	20.34	3.17	20.40	4.16	17.00	3.12	20.40	3.57	18.70
5.53	18.70	5.12	18.64	4.06	18.70	5.40	15.30	3.57	18.70	5.00	17.00
6.59	17.00	6.32	16.94	5.23	17.00	7.38	13.60	5.00	17.00	6.29	15.30
8.54	15.30	8.38	15.24	6.47	15.30	10.41	11.90	6.38	15.30	8.46	13.60
12.07	13.60	11.46	13.54	9.00	13.60	15.09	10.20	8.39	13.60	17.28	10.20
17.37	11.90	16.14	11.84	12.30	11.90	23.19	8.50	12.18	11.90	25.05	8.50
27.04	10.20	24.15	10.14	17.55	10.20	41.04	6.80	17.16	10.20	45.05	6.80
44.53	8.50	38.19	8.44	21.39	8.50	67.41	6.12	29.25	8.50	80.52	5.95
63.57	7.48	56.27	7.25	57.55	6.80	125.22	5.61	50.52	6.80	131.36	5.44
73.45	7.14	61.28	6.74	67.41	6.46	169.38	5.27	127.23	6.12		
81.59	6.80	108.05	6.06	125.08	5.78			137.34	5.44		
117.00	6.12	169.23	5.55	175.43	5.10						
177.18	5.44	280.21	5.04								
287.59	4.93										

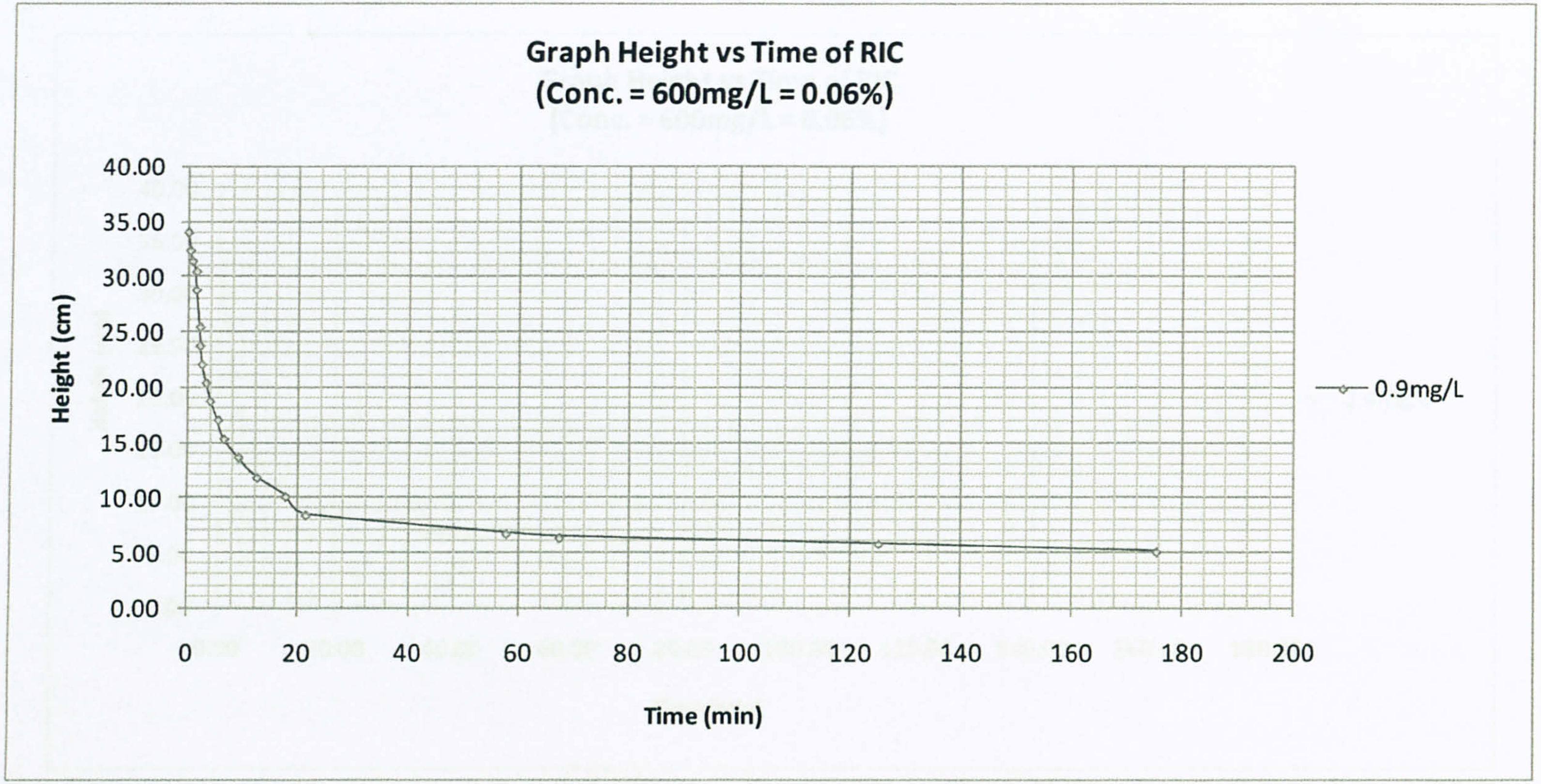


$$\frac{\Delta H}{\Delta T} = \frac{34 - 0}{11} = 3.09 cm/min$$

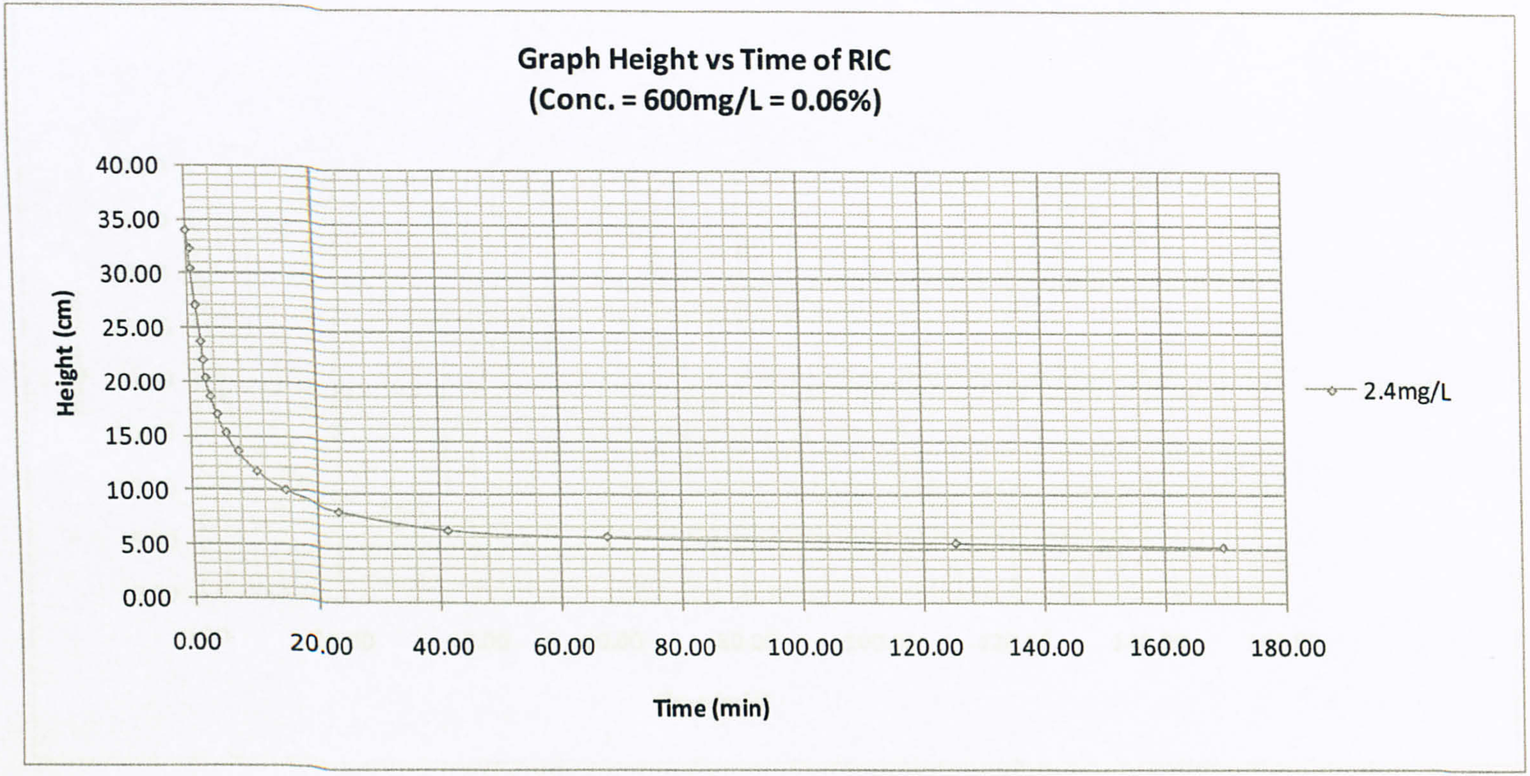
Appendix B6-2



$$\frac{\Delta H}{\Delta T} = \frac{34 - 0}{10} = 3.4cm/min$$

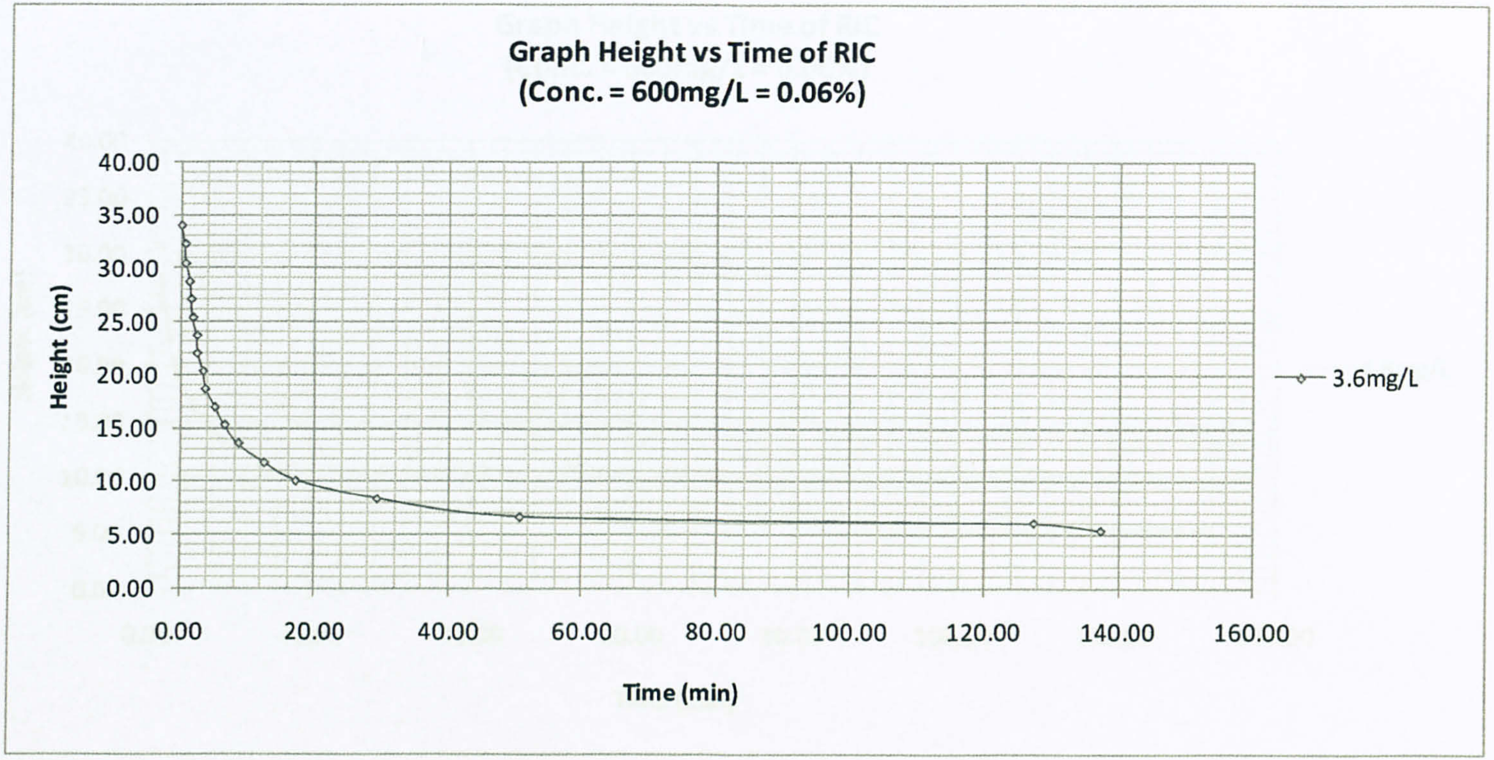


$$\frac{\Delta H}{\Delta T} = \frac{34 - 0}{6.6} = 5.15cm/min$$



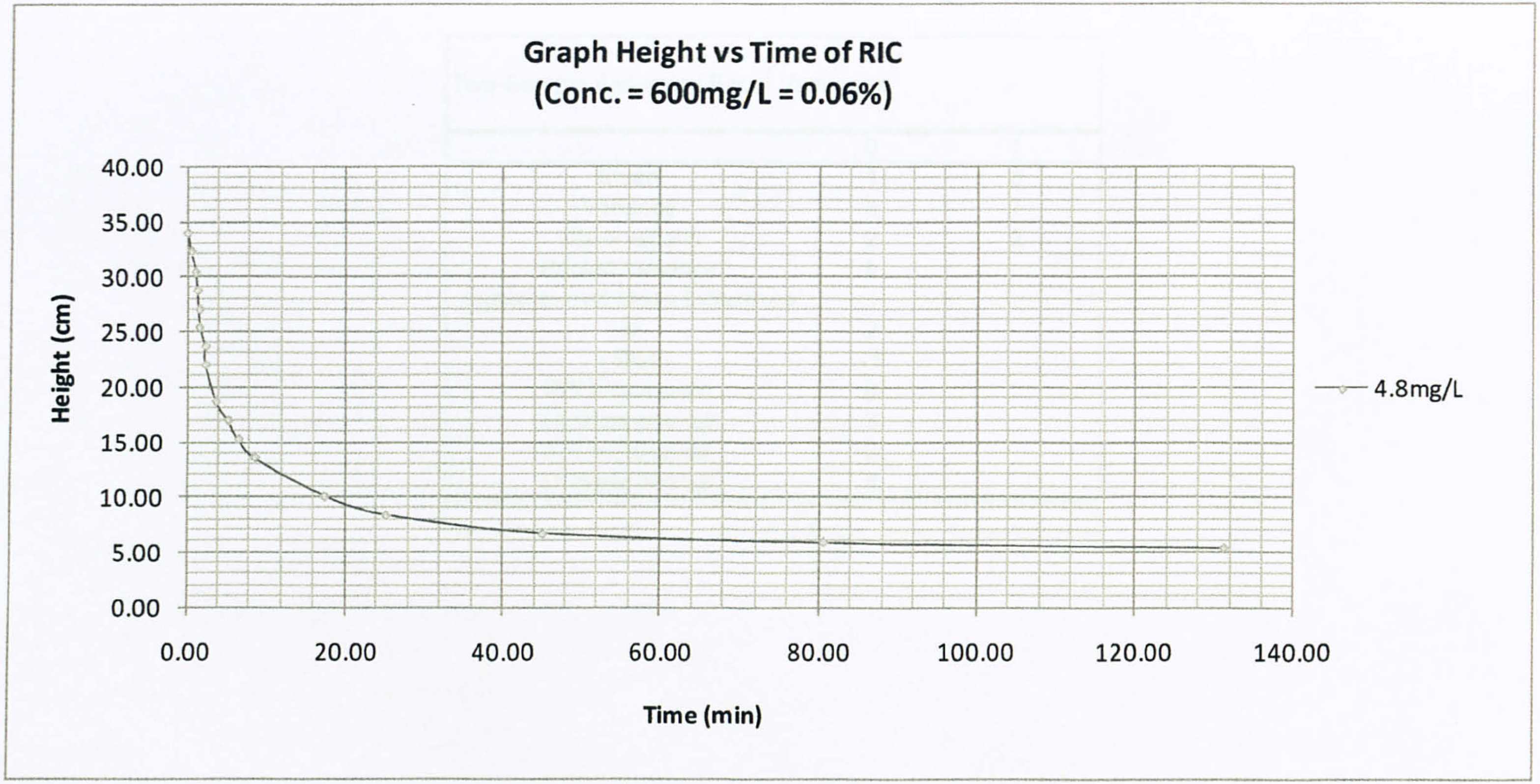
$$\frac{\Delta H}{\Delta T} = \frac{34-0}{6.6} = 5.15cm/min$$

Appendix B6-5



$$\frac{\Delta H}{\Delta T} = \frac{34 - 0}{7.7} = 4.41 cm/min$$

Appendix B6-6



$$\frac{\Delta H}{\Delta T} = \frac{34 - 0}{7} = 4.86cm/min$$

Appendix B7: t-Test Two Sample Assuming Variances

Two-Sample Assuming Equal Variances

	0	1
Mean	1	3
Variance	3	7
Observations	2	2
Pooled Variance	5	
Hypothesized Mean Difference	1	
df	2	
t Stat	-1	
P(T<=t) one-tail	0	
t Critical one-tail	3	
P(T<=t) two-tail	0	
t Critical two-tail	4	

Appendix C1: COD, Colour, and Turbidity Result for All Coagulants

Sample	Coagulant	Dosage (mg/L)	Volume (ml)	Grad. (cm/min)	COD (mg/l)				Colour (PtCO) - 455nm				Turbidity (NTU)			
					i	ii	iii	average	i	ii	iii	average	i	ii	iii	average
Raw	Nil	Nil	Nil	2.400	387	297	376	353	469	479	465	471	38.70	39.00	39.30	39.00
1-1	Alum	30	0.1	2.769	266	322	327	305	48	70	126	81	5.13	4.93	5.57	5.21
1-2	Alum	60	0.2	3.330	268	249	264	260	34	58	39	44	4.23	4.30	3.45	3.99
1-3	Alum	120	0.4	3.625	252	253	257	254	237	230	263	243	10.80	10.50	11.30	10.87
1-4	Alum	300	1	3.150	257	279	249	262	-9	-7	-9	-8	1.22	1.50	1.29	1.34
1-5	Alum	900	3	4.800	266	282	278	275	88	106	107	100	4.18	4.60	4.23	4.34
1-6	Alum	1200	4	4.750	248	291	249	263	216	224	223	221	9.74	9.90	9.89	9.84
2-1	Ferrous Sulphate	44.96	0.3	2.720	254	264	299	272	59	49	51	53	3.46	3.46	3.40	3.44
2-2	Ferrous Sulphate	89.93	0.6	2.150	334	356	297	329	24	31	38	31	3.79	3.69	3.57	3.68
2-3	Ferrous Sulphate	150	1	2.230	260	303	268	277	19	19	12	17	2.95	2.92	2.76	2.88
2-4	Ferrous Sulphate	299.7	2	3.110	258	249	249	252	58	81	108	82	5.27	6.02	6.17	5.82
2-5	Ferrous Sulphate	1049.2	7	3.170	272	465	299	345	356	365	368	363	10.10	10.30	10.40	10.27
2-6	Ferrous Sulphate	1498.8	10	3.750	295	355	434	361	293	272	260	275	11.90	11.10	10.30	11.10
3-1	Ferric Chloride	46.7	1	2.500	273	268	272	271	363	410	338	370	36.10	53.40	37.40	42.30
3-2	Ferric Chloride	93.4	2	3.110	272	281	324	292	291	330	286	302	21.20	25.00	19.60	21.93
3-3	Ferric Chloride	140.1	3	0.450	331	303	301	312	-2	8	3	3	1.20	1.12	0.86	1.06
3-4	Ferric Chloride	233.5	5	3.110	272	298	302	291	200	156	173	176	7.58	6.57	6.35	6.83
3-5	Ferric Chloride	934	20	2.900	442	459	334	412	144	148	161	151	6.34	6.29	6.45	6.36
3-6	Ferric Chloride	1401	30	3.875	401	398	504	434	71	70	79	73	3.60	3.39	3.35	3.45
M-1	RIC ($FeSO_4$)	0.12	0.2	3.090	236	377	245	286	397	395	366	386	35.20	34.70	35.60	35.17
M-2	RIC ($FeSO_4$)	0.3	0.5	3.400	233	227	233	231	905	797	801	834	139.00	108.00	106.00	117.67
M-3	RIC ($FeSO_4$)	0.9	1.5	5.150	240	236	246	241	167	150	169	162	13.50	12.60	14.60	13.57
M-4	RIC ($FeSO_4$)	2.4	4	5.150	260	256	313	276	280	270	244	265	13.30	12.00	12.20	12.50
M-5	RIC ($FeSO_4$)	3.6	6	4.410	250	321	244	272	157	140	115	137	7.29	5.50	5.86	6.22
M-6	RIC ($FeSO_4$)	4.8	8	4.860	261	275	252	263	123	140	201	155	7.20	8.42	11.60	9.07

Appendix C2: TSS Result for All Coagulants

Sample	Coagulant	Dosage (mg/L)	Volume (ml)	Weight before (g)			Weight after (g)			Differences (g)			Average (g)	TSS (mg/L)
				1	2	3	1	2	3	1	2	3		
Raw	Nil	Nil	Nil	1.4338	1.3847	1.4739	1.3156	1.2678	1.3334	0.1182	0.1169	0.1405	0.1252	1252.00
1_1	Alum	30	0.1	1.4276	1.4382	1.4401	1.3077	1.3197	1.2945	0.1199	0.1185	0.1456	0.1280	1280.00
1_2	Alum	60	0.2	1.4389	1.5072	1.3843	1.2754	1.3413	1.2686	0.1635	0.1659	0.1157	0.1484	1483.67
1_3	Alum	120	0.4	1.409	1.5216	1.3876	1.2934	1.2923	1.2748	0.1156	0.2293	0.1128	0.1526	1525.67
1_4	Alum	300	1	1.395	1.4232	1.4975	1.2837	1.3228	1.3183	0.1113	0.1004	0.1792	0.1303	1303.00
1_5	Alum	900	3	1.4459	1.5057	1.3982	1.3338	1.3333	1.2842	0.1121	0.1724	0.114	0.1328	1328.33
1_6	Alum	1200	4	1.612	1.3878	1.3643	1.4074	1.2898	1.2582	0.2046	0.098	0.1061	0.1362	1362.33
2_1	Ferrous Sulphate	44.96	0.3	1.4388	1.4399	1.4065	1.3229	1.3129	1.2926	0.1159	0.127	0.1139	0.1189	1189.33
2_2	Ferrous Sulphate	89.93	0.6	1.411	1.4919	1.5296	1.2727	1.3432	1.272	0.1383	0.1487	0.2576	0.1815	1815.33
2_3	Ferrous Sulphate	150	1	1.4086	1.4282	1.4016	1.2933	1.2907	1.2801	0.1153	0.1375	0.1215	0.1248	1247.67
2_4	Ferrous Sulphate	299.7	2	1.378	1.4239	1.4165	1.2771	1.3234	1.3176	0.1009	0.1005	0.0989	0.1001	1001.00
2_5	Ferrous Sulphate	1049.2	7	1.4265	1.4628	1.4275	1.3304	1.3331	1.2874	0.0961	0.1297	0.1401	0.1220	1219.67
2_6	Ferrous Sulphate	1498.8	10	1.4909	1.4145	1.3945	1.2669	1.3046	1.2663	0.224	0.1099	0.1282	0.1540	1540.33
3_1	Ferric Chloride	46.7	1	1.4328	1.4023	1.4667	1.3182	1.2742	1.3303	0.1146	0.1281	0.1364	0.1264	1263.67
3_2	Ferric Chloride	93.4	2	1.4725	1.414	1.4302	1.3379	1.3003	1.2965	0.1346	0.1137	0.1337	0.1273	1273.33
3_3	Ferric Chloride	140.1	3	1.4758	1.4573	1.4812	1.3328	1.3324	1.3472	0.143	0.1249	0.134	0.1340	1339.67
3_4	Ferric Chloride	233.5	5	1.3433	1.3806	1.4729	1.1945	1.242	1.345	0.1488	0.1386	0.1279	0.1384	1384.33
3_5	Ferric Chloride	934	20	1.4748	1.3895	1.4075	1.2745	1.2718	1.2811	0.2003	0.1177	0.1264	0.1481	1481.33
3_6	Ferric Chloride	1401	30	1.4963	1.4333	1.439	1.3824	1.2818	1.2822	0.1139	0.1515	0.1568	0.1407	1407.33
M_1	RIC (FeSO4)	0.12	0.2	1.4727	1.5585	1.4594	1.3332	1.3137	1.3009	0.1395	0.2448	0.1585	0.1809	1809.33
M_2	RIC (FeSO4)	0.3	0.5	1.6537	1.4461	1.4248	1.4225	1.3396	1.286	0.2312	0.1065	0.1388	0.1588	1588.33
M_3	RIC (FeSO4)	0.9	1.5	1.5002	1.4094	1.4564	1.3046	1.2947	1.279	0.1956	0.1147	0.1774	0.1626	1625.67
M_4	RIC (FeSO4)	2.4	4	1.5008	1.4726	1.4321	1.2874	1.3394	1.3233	0.2134	0.1332	0.1088	0.1518	1518.00
M_5	RIC (FeSO4)	3.6	6	1.4442	1.4722	1.3855	1.3349	1.3378	1.2805	0.1093	0.1344	0.105	0.1162	1162.33
M_6	RIC (FeSO4)	4.8	8	1.3814	1.4515	1.385	1.2686	1.2903	1.2678	0.1128	0.1612	0.1172	0.1304	1304.00

Appendix D1: Leachate Treatment using RFS

RFS 0.035	350	80000	(Leachate - without adjusting pH)						
Jar Number	Dosage (mg/L)	Dosage (mg/L)	Vol of coagulant	pH	pH Final	Total COD (mg/L) - Dilution 1:10			
						i	ii	iii	Average
1.00	**0.70**	**160.00**	2.00	8.50	8.12	3575	3564	3553	3564
2.00	**1.40**	**320.00**	4.00	8.50	7.80	3377	3366	3355	3366
3.00	**7.00**	**1600.00**	20.00	8.50	6.73	2882	2871	2860	2871
4.00	**10.50**	**2400.00**	30.00	8.50	6.41	2497	2486	2475	2486
5.00	**21.00**	**4800.00**	60.00	8.50	4.63	1320	1331	1320	1324
6.00	**35.00**	**8000.00**	100.00	8.50	2.16	2519	2530	2508	2519

RFS 0.035	350	80000	(Leachate - without adjusting pH)										
Jar Number	Dosage (mg/L)	Dosage (mg/L)	Vol of coagulant	pH	pH Final	TSS (mg/L)				Colour (PtCo) - 465nm - Dilution 1:100			
						i	ii	iii	Average	i	ii	iii	Average
1.00	**0.70**	**160.00**	2.00	8.50	8.12	**4070**	**4114**	**3718**	**3967**	8484	8383	8080	**8316**
2.00	**1.40**	**320.00**	4.00	8.50	7.80	2510	3704	2704	**2973**	8585	8181	8282	**8349**
3.00	**7.00**	**1600.00**	20.00	8.50	6.73	2724	2468	2574	**2589**	6565	5858	6363	**6262**
4.00	**10.50**	**2400.00**	30.00	8.50	6.41	3100	3052	4024	**3392**	4242	4444	7979	**5555**
5.00	**21.00**	**4800.00**	60.00	8.50	4.63	3130	2148	4848	**3375**	606	303	404	**438**
6.00	**35.00**	**8000.00**	100.00	8.50	2.16	2426	3044	3166	**2879**	8080	7373	7777	**7743**

Appendix D2: Jar Test Result for RFS (pH Variation)

Jar Test (250308)

Leachate Treatment Using RFS (Variable pH)

pH for raw leachate = **8.6**
RFS Conc. = **350 mg/L (0.035%)**

Results:

Sample	Initial Ph	Final Ph	Coagulant	Dosage (mg/L)	Volume (ml)	COD (mg/l) - Dilution 1:100			
						i	ii	iii	average
1	3.0	2.0	RFS	7	10	3232	2525	4545	3,434
2	6.0	2.0	RFS	7	10	5454	5353	5454	5,420
3	7.0	6.7	RFS	7	10	6767	6060	6363	6,397
4 (Raw)	8.6	6.9	RFS	7	10	6363	5959	5757	6,026
5	9.0	7.3	RFS	7	10	6464	6262	5757	6,161
6	10.0	9.5	RFS	7	10	5959	6262	5858	6,026

Sample	Initial Ph	Final Ph	Coagulant	Dosage (mg/L)	Volume (ml)	Colour (PtCO) - 455nm - Dilution 1:500			
						i	ii	iii	average
1	3.0	2.0	RFS	7	10	1503	2505	4008	2,672
2	6.0	2.0	RFS	7	10	501	2004	2505	1,670
3	7.0	6.7	RFS	7	10	4509	2004	3507	3,340
4 (Raw)	8.6	6.9	RFS	7	10	3006	2505	0	2,756
5	9.0	7.3	RFS	7	10	-1503	4509	3507	4,008
6	10.0	9.5	RFS	7	10	4008	2004	3507	3,173

Sample	Weight before (g)			Weight after (g)			Differences (g)			Average (g)	TSS (mg/L)
	1	2	3	1	2	3	1	2	3		
1	1.5144	1.4800	1.4649	1.2712	1.3134	1.2733	0.2432	0.1666	0.1916	0.2005	2005
2	1.9040	1.4917	1.8872	1.3349	1.3212	1.3466	0.5691	0.1705	0.5406	0.4267	4267
3	1.4850	1.5170	1.5399	1.2800	1.3094	1.3364	0.2050	0.2076	0.2035	0.2054	2054
4 (Raw)	1.5626	1.4732	1.5721	1.3231	1.2685	1.3293	0.2395	0.2047	0.2428	0.2290	2290
5	1.7955	1.7055	1.8606	1.3255	1.3142	1.4495	0.4700	0.3913	0.4111	0.4241	4241
6	1.5210	1.7932	1.4947	1.3458	1.3350	1.3325	0.1752	0.4582	0.1622	0.2652	2652

Appendix D3: Jar Test Result for Alum, $FeSO_4$ and $FeCl_3$ (pH Variation).

Alum 30% 300000

Jar Number	Dosage (mg/L)	Vol of coagulant	pH	pH Final	Total COD (mg/L) - Dilution 1:10				TSS (mg/L)				Colour (PtCo) Dilution 1:250			
					i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1	**600**	2.00	2.39	2.37	3069	3135	3047	3084	4540	3904	3932	**4125**	3263	3514	3765	**3514**
2	**600**	2.00	3.89	3.61	3322	3212	3256	3263	2062	2900	3738	**2481**	6777	7028	6777	**6861**
3	**600**	2.00	6.66	6.65	3267	3322	3410	3333	1416	1400	4684	**1408**	4267	3514	3765	**3849**
4	**600**	2.00	7.25	7.15	3421	3322	3509	3417	2146	2180	2234	**2207**	5271	5020	5020	**5104**
5	**600**	2.00	8.08	7.90	3311	3465	3641	3472	3828	3968	4588	**3898**	4769	5020	4769	**4853**
6	**600**	2.00	9.88	9.82	3377	3399	3366	3381	5646	5138	5438	**5407**	9036	8534	5773	**8785**
6																

Ferrous Sulphate 3% 30000

Jar Number	Dosage (mg/L)	Vol of coagulant	pH	pH Final	Total COD (mg/L) - Dilution 1:10				TSS (mg/L)				Colour (PtCo) Dilution 1:10			
					i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1	**30**	1.00	2.95	2.88	3170	3120	3270	3187	4350	4162	4408	**4307**	2761	2750	2739	2745
2	**30**	1.00	4.94	4.83	3490	3540	3590	3540	4926	5066	4526	**4996**	4906	4983	4983	**4957**
3	**30**	1.00	6.10	5.82	3400	3490	3400	3430	5468	5462	5066	**5465**	5764	5786	5852	**5801**
4	**30**	1.00	6.90	6.79	3600	3500	3570	3557	5042	5400	3734	**5221**	7436	7447	7524	**7469**
5	**30**	1.00	8.08	7.96	3450	3460	3440	3450	3132	3603	1537	**3368**	8085	7986	8041	**8037**
6	**30**	1.00	9.92	9.80	3500	3400	3530	3515	3592	3578	3842	**3671**	6160	6116	6127	**6134**
6																

Ferric Chloride 30%

Jar Number	Dosage (mg/L)	Vol of coagulant	pH	pH Final	Total COD (mg/L) - Dilution 1:100				TSS (mg/L)				Colour (PtCo) - 465nm - Dilution 1:100			
					i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1	**600**	1.00	1.85	2.00	4141	3636	3737	3838	**3750**	**3984**	**4134**	**3956**	4747	4444	4343	4511
2	**600**	1.00	2.69	2.93	3434	3636	4343	3535	3470	3488	3662	**3540**	5959	6161	6161	6094
3	**600**	1.00	3.83	2.87	3232	2525	2828	2677	4838	3732	3954	**3843**	3333	3939	4949	4074
4	**600**	1.00	5.89	4.20	909	1313	909	1044	4106	2567	2706	**2637**	1515	1313	1212	1347
5	**600**	1.00	7.22	6.53	5050	4646	4444	4713	4270	5244	6074	**5659**	2727	3030	2727	2828
6	**600**	1.00	9.11	8.30	5151	4545	4747	4814	3564	4968	5074	**5021**	3737	3535	3232	3501
6																

Appendix D4: Jar Test Result for RFS, Alum, $FeSO_4$ and $FeCl_3$ (At Optimum pH).

RFS	350	80000		ph=6													
Jar Number	Dosage (mg/L)	Dosage (mg/L)	Vol of coagulant (mL)	pH	pH Final	Total COD (mg/L) - Dilution 1:10				TSS (mg/L)				Colour (PtCo)			
						i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1	0.7	160	2.00	6.06	6.08	3366	3355	3289	3337	4094	4120	3676	4107	3765	4016	3514	3765
2	1.4	320	4.00	6.45	6.55	3168	3300	3223	3230	3550	4014	2950	3782	3263	3765	2510	3179
3	7	1600	20.00	6.68	4.78	1705	1705	1595	1668	5802	5680	4164	5741	2510	2008	2259	2259
4	10.5	2400	30.00	6.58	3.42	2211	2112	2134	2152	2122	1882	2954	2002	2761	3263	3765	3263
5	14	3200	40.00	6.64	3.09	2266	2343	2189	2266	3440	3580	2866	3510	4016	4518	3514	4016
6	21	4800	60.00	6.65	2.69	2805	2761	2618	2728	4648	4284	2490	4466	3765	4769	3765	4100
6																	

Ferric Chloride	300000			ph=6													
Jar Number	Dosage (mg/L)		Vol of coagulant (mL)	pH	pH Final	Total COD (mg/L) - Dilution 1:100				TSS (mg/L)				Colour (PtCo) - 465nm - Dilution 1:100			
						i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1.00	30		0.05	6.00	7.07	5151	4646	1717	4899	3466	3906	4406	3926	5050	5555	4949	5185
2.00	600		1.00	6.00	6.74	3434	3636	3737	3602	3802	4198	4040	4013	4242	2929	2929	2929
3.00	1800		3.00	6.00	6.05	2222	2323	3232	2273	4472	4472	5790	4472	1919	2424	3030	2458
4.00	3000		5.00	6.00	2.94	1919	2525	5656	2222	3838	3372	3446	3552	8484	9696	9393	9191
5.00	6000		10.00	6.00	2.42	1010	808	909	909	8754	12894	434	10824	17372	18483	17574	17810
6.00	12000		20.00	6.00	2.33	2008	1004	1255	1422	3934	3826	4122	3961	10807	14645	15150	13534

Alum	300000			ph=6													
Jar Number	Dosage (mg/L)		Vol of coagulant (mL)	pH	pH Final	Total COD (mg/L) - Dilution 1:100				TSS (mg/L)				Colour (PtCo) - 465nm - Dilution 1:100			
						i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1.00	30		0.10	6.00	6.52	5151	5252	5555	5319	3838	4218	3098	4028	3939	4848	4242	4343
2.00	300		1.00	6.00	6.45	6262	4949	5353	5521	3524	3862	4060	3815	5151	4545	4141	4612
3.00	1500		5.00	6.00	6.24	4646	5151	5050	4949	3864	3362	4208	3811	2929	2626	1515	2357
4.00	3000		10.00	6.00	5.98	3535	4141	3737	3804	3614	4002	3370	3662	1212	1212	909	1111
5.00	4500		15.00	6.00	5.81	2323	2828	5656	2576	4232	4152	3288	4192	202	404	505	370
6.00	12000		40.00	6.00	4.30	2424	2424	3030	2626	4124	4282	4450	4285	909	909	1111	976

Ferrous Sulphate 3%	30000																
Jar Number	Dosage (mg/L)		Vol of coagulant (mL)	pH	pH Final	Total COD (mg/L) - Dilution 1:10				TSS (mg/L)				Colour (PtCo) Dilution 1:100			
						i	ii	iii	Average	i	ii	iii	Average	i	ii	iii	Average
1	60		1.00	5.93	6.00	6969	6161	5959	6363	2954	4872	5170	4332	6868	7676	6767	7222
2	300		5.00	5.92	6.00	6060	6161	6363	6195	8016	4956	4092	6486	28381	28583	29189	28718
3	600		10.00	6.08	6.15	6363	5353	6767	6161	4264	6926	9824	5595	23735	23028	249473	98745
4	1200		20.00	6.17	6.20	5555	5050	6868	5824	5368	6428	5982	5898	25856	25755	26058	25890
5	3000		50.00	6.10	6.40	5353	5656	6060	5690	7270	7666	4884	7468	10201	9696	9595	9831
6	6000		100.00	6.10	6.61	5757	6161	6161	5959	11236	12543	12900	12226	29694	30502	12726	24307
6																	